Opequon Watershed TMDLs
for Benthic Impairments:
Abrams Creek and Lower Opequon Creek, Frederick and Clarke Counties, Virginia

Submitted by:

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

Stream segments on Abrams Creek (Segment ID: VAV-B09R_ABR01A00) and the Lower Opequon Creek (Segment ID: VAV-B09R_OPE01A00) are both listed as impaired on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998 and 2002) due to water quality violations of the General Standard (listed as a benthic impairment).

Both Abrams Creek and the Lower Opequon Creek are contained within the larger Opequon Creek watershed, which will need to be considered in its entirety in order to estimate loads to the impaired segment of Lower Opequon Creek. A part of the Potomac and Shenandoah River basin, the Opequon Creek watershed is located in Frederick and Clarke Counties, Virginia, and encompasses the City of Winchester. The watershed is 36,321 ha (89,749 acres) in size. For description purposes, the Opequon Creek watershed has been sub-divided into 3 non-overlapping component areas – Abrams Creek watershed, Upper Opequon Creek watershed, and the Lower Opequon Remnant, as shown in Figure 1.1. The name - Lower Opequon Remnant – was given to

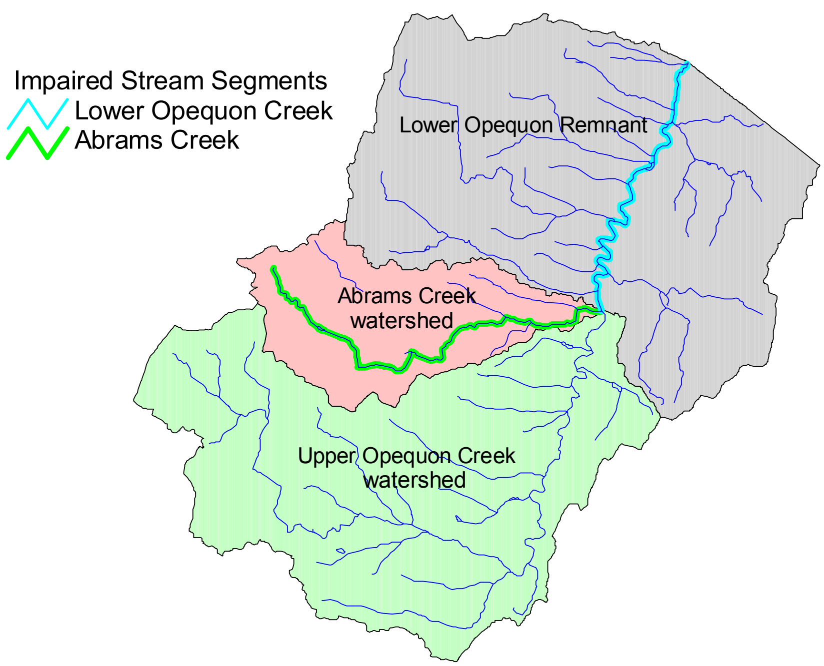

Figure 1.1. Opequon Creek Component Areas and Impaired Stream Segments

this area because, although the whole watershed drains to the Lower Opequon, this portion is a downstream portion that is left over once the other two headwater sub-watersheds are separated out. The Lower Opequon Remnant contains the outlet of the Opequon Creek watershed and receives flow from the two headwater watersheds – Abrams Creek and the Upper Opequon Creek. In the state watershed classification scheme, Opequon Creek is comprised of hydrologic units B08 and B09. B08 corresponds with the Upper Opequon Creek watershed, while B09 contains both the Abrams Creek watershed and the Lower Opequon Remnant, and is named the Lower Opequon Creek watershed.

1.1.1. Abrams Creek

Abrams Creek is listed as impaired for a stream length of 10.80 miles. The impaired segment begins at the headwaters and continues downstream to its confluence with Opequon Creek. Biological monitoring has been performed by VADEQ in the Abrams Creek watershed from October 1994 to October 2001 at the ABR000.78 benthic monitoring site. During this period, all 7 benthic samples were rated as “moderately” impaired. This monitoring is supplemented by ambient water quality monitoring at the same location and special study sites.

Abrams Creek watershed is located in Frederick County, Virginia, encompassing the majority of the City of Winchester (Figure 2.2). The watershed is 4,972 ha (12,287 acres) in size. Abrams Creek is mainly an urban watershed (50.7%) and is characterized by a rolling valley with the Little North Mountain (Appalachian) to the west and the Blue Ridge Mountains to the east. The remaining watershed area is divided between forest (21.9%) and agricultural (27.4%) land uses. Abrams Creek is a tributary of Opequon Creek, which in turn, is tributary to the Potomac River. The Potomac River then discharges into the Chesapeake Bay.

1.1.2. Lower Opequon Creek

Lower Opequon Creek is listed as impaired for a stream length of 8.82 miles. The impaired segment begins at the confluence with Abrams Creek and Upper Opequon Creek and continues downstream to the West Virginia state line. Biological monitoring has been performed by VADEQ in the Lower Opequon Creek watershed from October 1994 to May 2002 at the OPE029.61 benthic monitoring site. During this period, 7 of the

9 benthic samples were rated as "moderately" impaired, with the remainder receiving a rating of "slightly" impaired. This monitoring was supplemented by ambient water quality monitoring at the downstream OPE025.10 monitoring site.

The Lower Opequon Remnant is located in both Frederick and Clarke Counties, Virginia, downstream from the confluence of the Upper Opequon Creek with Abrams Creek. The watershed is 16,405 ha (40,537 acres) in size. The Lower Opequon Remnant is mainly an agricultural area (64.4%) with a small but increasing amount of urban and commercial land uses (9.2%), and the remainder in forest. The area is also characterized by a rolling valley with the Appalachian Mountains to the west and the Blue Ridge Mountains to the east. Lower Opequon Creek is a tributary of the Potomac River, which in turn discharges into the Chesapeake Bay.

1.2. Benthic Stressor Analysis

Since a benthic impairment is based on a biological inventory, rather than on physical or chemical water quality parameters, the pollutant is not implicitly identified in the assessment, as it is with physical or chemical parameters. The process outlined in EPA's *Stressor Identification Guidance Document* (EPA, 2000) was used to identify the most probable stressor(s) for Abrams Creek and for Lower Opequon Creek. Analyses of physical, chemical, biological, and observational data indicated that sediment was the most probable cause of the benthic impairments in both stream segments. TMDLs were therefore developed for sediment to address the benthic impairments in Abrams Creek and Lower Opequon Creek.

1.3. Sources of Sediment

Sediment is delivered to the impaired segments of Abrams Creek and Lower Opequon Creek through the processes of surface runoff, channel and streambank erosion, and from point source inputs, as well as from background geologic forces. Natural sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, and urban land uses. During runoff events, sediment loading occurs from both pervious and impervious surfaces in the watershed. Streambank erosion is caused by reduction in riparian cover and increased human-induced activities on these areas. Animals grazing on pastures in riparian areas with access to streams also contribute to streambank erosion. Existing total suspended sediment loads from permitted dischargers were calculated from monthly Discharge Monitoring Report data, from General Permit limits, and from model output for the MS4 aggregate load, as shown in Tables 1.1 and 1.2 for Abrams Creek and the entire Opequon Creek watersheds, respectively. Hardening of stream channels, as observed along much of Town Run, reduces upstream channel scour but increases scour downstream. Transport of sediment is further increased by increasing areas of imperviousness in a watershed from urban growth and development, which increase the flow volume and peak rates of surface runoff.

Table 1.1. Abrams Creek Existing Loads from Permitted TSS Dischargers

VPDES ID	Name	DMR Maximum Daily Flow (MGD)	DMR Maximum Daily [TSS] (mg/L)	Existing Annual Load (t/yr)
VA0002739	Perry, S. M.[1]	0.09900	3.00	0.410
VA0051373	National Fruit[1]	0.03200	5.00	0.221
VA0076384	Abex[1]	0.21470	3.06	0.909
0 - Single Family General Permit 1000 gpd Units[2]		0.001	30	0.000
VAR040053	City of Winchester[3]			527.0
VAR040032	VDOT - Winchester Urban Area[3]			
Existing TSS Load From Permitted Dischargers				**528.5**

[1] The existing TSS load from permitted dischargers is calculated from the average of all monthly reported maximum daily flow and maximum daily concentration.

[2] General Permit Loads are calculated as the number of units (0) multiplied by the maximum daily flow (1000 gpd) and the maximum TSS concentration (30 mg/L).

[3] Existing loads in MS4 areas are calculated as the modeled loads from urban transitional and impervious areas within the City limits.

Table 1.2. Opequon Creek Existing Loads from Permitted TSS Dischargers

VPDES ID	Name	DMR Maximum Daily Flow (MGD)	DMR Maximum Daily [TSS]	Existing Annual Load (t/yr)
VA0002739	Perry, S. M.[1]	0.09900	3.00	0.410
VA0023116	I-81 Rest Area STP[1]	0.00500	8.89	0.061
VA0027600	A & K Car Wash[1]	0.00100	23.09	0.032
VA0029653	Shalom et Benedictus Lagoon[1]	0.00300	19.32	0.080
VA0051373	National Fruit[1]	0.03200	5.00	0.221
VA0065552	Opequon Regional AWT[1]	4.80000	2.96	19.618
VA0075191	Parkins Mill STP[1]	1.21500	3.18	5.342
VA0076384	Abex[1]	0.21470	3.06	0.909
VA0088471	Frederick Co. Landfill[1]	0.14200	15.13	2.968
VA0088722	Stonebrook Swim Club[1]	0.00087	2.61	0.003
VA0089010	Franciscan Center[1]	0.00013	4.40	0.001
VA0090808	APAC Virginia WWTP[1]			
45 - Single Family General Permit 1000 gpd Units[2]		0.001	30	1.865
VAR040053	City of Winchester[3]			336.2
VAR040032	VDOT - Winchester Urban Area[3]			
Existing TSS Load From Permitted Dischargers				**367.7**

[1] The existing TSS load from permitted dischargers is calculated from the average of all monthly reported maximum daily flow and maximum daily concentration.

[2] General Permit Loads are calculated as the number of units (45) multiplied by the maximum daily flow (1000 gpd) and the maximum TSS concentration (30 mg/L).

[3] Existing loads in MS4 areas are calculated as the modeled loads from urban transitional and impervious areas within the City limits.

1.4. Modeling

Because Virginia has no numeric in-stream criteria for sediment, a “reference watershed” approach was used to define allowable TMDL loading rates in the impaired watershed. The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired.

The Upper Opequon Creek watershed was selected as the TMDL reference for both Abrams Creek and Lower Opequon Creek. The TMDL sediment target load was defined as the modeled sediment load for existing conditions from the non-impaired Upper Opequon watershed, area-adjusted separately to each of the two impaired watersheds. Reductions in sediment load from each impaired watershed to the TMDL target loads are expected to allow benthic conditions to return to a non-impaired state. The sediment load to the Lower Opequon Creek impaired stream segment was modeled from the entire drainage upstream from its outlet, which is the Opequon Creek watershed, minus a small area that drains into West Virginia outside the main channel.

The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was selected for comparative modeling for both sets of impaired and reference watersheds in these TMDL studies. The GWLF model was calibrated for hydrology separately for the Abrams Creek watershed and the Upper Opequon Creek TMDL reference watershed. The calibration parameters from Abrams Creek and Upper Opequon Creek were area-weighted and applied to the Lower Opequon Remnant where flow data were not available for calibration.

1.5. Benthic TMDLs for Sediment

1.5.1. Abrams Creek TMDL

The benthic TMDL for the Abrams Creek watershed was developed using sediment as the pollutant and the Upper Opequon Creek watershed as the TMDL reference watershed. Since the Upper Opequon Creek watershed was larger than Abrams Creek, the area of each land use in the Upper Opequon watershed was reduced in proportion to the ratio of the area of the impaired watershed to that of the TMDL reference watershed (x 0.334). This resulted in an area-adjusted Upper Opequon watershed equal in size with the land area in the impaired Abrams Creek watershed (4,952 ha). The average annual sediment load in metric tons per year (t/yr) from the area-adjusted Upper Opequon Creek defined the TMDL sediment load for Abrams Creek in Table 1.3. Loads were based on average annual sediment loads using the 6-yr period, January 1982 – December 1987, as representative of both wet and dry periods of precipitation.

Table 1.3. Abrams Creek TMDL - Existing Sediment Loads (t/yr)

	Abrams Creek			Area-adjusted Upper Opequon Creek		
Sediment Sources	**(t/yr)**	**(%)**	**(t/ha)**	**(t/yr)**	**(%)**	**(t/ha)**
High Till	764.8	8.6%	39.48	2,362.7	37.3%	15.55
Low Till	253.9	2.9%	17.17	1,056.9	16.7%	9.08
Pasture	320.1	3.6%	0.31	561.6	8.9%	0.24
Urban grasses	441.3	5.0%	0.89	97.9	1.5%	0.83
Orchards	24.8	0.3%	0.09	12.2	0.2%	0.06
Forest	36.1	0.4%	0.03	50.0	0.8%	0.04
Transitional	452.8	5.1%	9.36	504.7	8.0%	14.39
Pervious Urban	146.3	1.6%	0.16	46.3	0.7%	0.16
Impervious Urban	290.5	3.3%	0.28	167.5	2.6%	0.62
MS4	527.0	5.9%		0.0	0.0%	
Other Permitted Point Sources	1.5	0.0%		3.0	0.0%	
Channel Erosion	5,648.3	63.4%	1.14	1,464.5	23.1%	0.30
Watershed Totals	**8,907.4**	100.0%		**6,327.3**	100.0%	
			Target Sediment TMDL Load =	**6,327**		**t/yr**
			10% MOS =	633		t/yr
			Load for Allocation =	**5,695**		**t/yr**

The benthic TMDL for Abrams Creek is comprised of the three required sediment load components - the waste load allocation (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), each of which is quantified in Table 1.4. An explicit 10% margin of safety (MOS) was included in the calculation.

Table 1.4. Abrams Creek TMDL Sediment Goal (t/yr)

TMDL	WLA	LA	MOS
6,327.3	470.1	5,224.4	632.7

The waste load allocation (WLA) was calculated as the sum of all permitted TSS loads, as detailed in Table 1.5. The load allocation (LA) - the allowable sediment load from nonpoint sources - was calculated as the target TMDL load minus the MOS minus the WLA.

Table 1.5. Abrams Creek TMDL Sediment WLA Allocations (t/yr)

VPDES ID	Name	Permitted Design Flow (MGD)	Permitted Monthly Ave Conc (mg/L)	WLA (t/yr)
VA0002739	Perry, S. M.[1]	0.10	30	4.15
VA0051373	National Fruit[1]	0.06	30	2.49
VA0076384	Abex[1]	0.50	30	20.73
0 - Single Family General Permit 1000 gpd Units[2]		0.001	30	0.00
VAR040053	City of Winchester[3]			442.7
VAR040032	VDOT - Winchester Urban Area[3]			
WLA Total				**470.1**

[1] WLA was calculated from the permitted design flow and the permitted monthly average concentration.

[2] General Permit Loads are calculated as the number of units (0) multiplied by the maximum daily flow (1000 gpd) and the maximum TSS concentration (30 mg/L).

[3] MS4 loads were assigned in aggregate based on the allocation reductions to the modeled loads from urban transitional and impervious areas within the watershed and inside City limits.

1.5.2. Lower Opequon Creek TMDL

The benthic TMDL for the Lower Opequon Creek watershed was developed, also using sediment as the target pollutant and the Upper Opequon Creek watershed as its TMDL reference watershed. The entire Opequon Creek watershed contributes to the impaired segment on Lower Opequon Creek and was considered in the modeling process to be the impaired watershed. Since the Upper Opequon Creek watershed is a component of the larger Opequon Creek watershed, the area of each land use in the Upper Opequon watershed was increased in proportion to the ratio of the area of the impaired watershed to that of the TMDL reference watershed (x 2.434). This resulted in an area-adjusted Upper Opequon watershed equal in size with the land area of the impaired Lower Opequon Creek watershed (36,133 ha). The average annual sediment load (t/yr) from the area-adjusted Upper Opequon Creek defined the TMDL sediment load for Lower Opequon Creek in Table 1.6. Loads were based on average annual sediment loads using the 6-yr period, January 1982 – December 1987, as representative of both wet and dry periods of precipitation.

Table 1.6. Lower Opequon Creek TMDL - Existing Sediment Loads

Sediment Sources	**Opequon Creek (t/yr)**	**(%)**	**(t/ha)**	**Area-adjusted Upper Opequon Creek (t/yr)**	**(%)**	**(t/ha)**
High Till	8,690.5	15.1%	8.65	9,605.9	17.9%	8.66
Low Till	2,868.7	5.0%	3.73	3,323.6	6.2%	3.91
Pasture	1,964.9	3.4%	0.11	2,092.2	3.9%	0.12
Urban grasses	532.1	0.9%	0.50	425.4	0.8%	0.50
Orchards	50.4	0.1%	0.04	54.2	0.1%	0.04
Forest	93.4	0.2%	0.01	172.0	0.3%	0.02
Transitional	1,657.7	2.9%	6.50	1,314.6	2.4%	5.14
Pervious Urban	239.8	0.4%	0.10	205.3	0.4%	0.10
Impervious Urban	1,153.1	2.0%	0.48	1,222.0	2.3%	0.62
MS4	336.2	0.6%		0.0	0.0%	
Other Permitted Point Sources	31.51	0.1%		21.8	0.0%	
Channel Erosion	40,029.6	69.4%	1.11	35,324.5	65.7%	0.98
Watershed Total	**57,647.8**	100.0%		**53,761.4**	100.0%	
			Target Sediment TMDL Load =	**53,761.4**		**t/yr**
			10% MOS =	5,376.1		t/yr
			Load for Allocation =	**48,385.3**		**t/yr**

The benthic TMDL for the Lower Opequon Creek is comprised of the three sediment load required components - the waste load allocation (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), each of which is quantified in Table 1.7.

Table 1.7. Lower Opequon Creek TMDL Sediment Goal (t/yr)

TMDL	**WLA**	**LA**	**MOS**
53,761.4	892.3	47,493.0	5,376.1

The margin of safety (MOS) was explicitly defined as 10% of the calculated TMDL, as with Abrams Creek. The waste load allocation (WLA) was calculated as the sum of all maximum permitted TSS loads, as detailed in Table 1.8. The load allocation (LA) - the allowable sediment load from nonpoint sources - was calculated as the target TMDL load minus the MOS minus the WLA. Since the MOS is excluded from allocation, the target load for modeling purposes in Lower Opequon Creek becomes the TMDL minus the MOS (48,385.3 t/yr). MS4 loads from Abrams Creek that were counted in the Lower Opequon were reduced by applying a ratio (0.55) to account for the different upstream drainage areas in the two watersheds used in calculating watershed sediment delivery ratios.

Table 1.8. Lower Opequon Creek Sediment WLA Allocations (t/yr)

VPDES ID	Name	Permitted Average Daily Load (kg/day)	Permitted Design Flow (MGD)	Permitted Monthly Ave Conc (mg/L)	WLA (t/yr)
VA0002739	Perry, S. M.[1]		0.10	30	4.15
VA0023116	I-81 Rest Area STP[1]	1.36	0.02	24	0.50
VA0027600	A & K Car Wash[1]		0.01	60	0.41
VA0029653	Shalom et Benedictus Lagoon[1]	0.80	0.01	30	0.29
VA0051373	National Fruit[1]		0.06	30	2.49
VA0065552	Opequon Regional AWT[1]	1386	12.2	30	506.05
VA0075191	Parkins Mill STP[1]	227	2.0		82.91
VA0076384	Abex[1]		0.50	30	20.73
VA0088471	Frederick Co. Landfill[1]	9.08	0.08		3.32
VA0088722	Stonebrook Swim Club[1]	0.45			0.16
VA0089010	Franciscan Center[1]	0.18		30	0.07
VA0090808	APAC Virginia WWTP[1]	0.60	0.01	30	0.22
45 - Single Family General Permit 1000 gpd Units[2]			0.001	30	1.87
VAR040053	City of Winchester[3]				269.2
VAR040032	VDOT - Winchester Urban Area[3]				
WLA Total					**892.3**

[1] The existing TSS load from permitted dischargers is calculated from the average of all monthly reported maximum daily flow and maximum daily concentration.

[2] General Permit Loads are calculated as the number of units (45) multiplied by the maximum daily flow (1000 gpd) and the maximum TSS concentration (30 mg/L).

[3] Existing loads in MS4 areas are calculated as the modeled loads from urban transitional and impervious areas within the City limits.

1.6. Projected Future Conditions

The Opequon Creek watershed is experiencing urban development and growth, so changes in land use must be estimated for modeling future loads as part of the TMDL allocation procedure. Future land use scenarios were created based on projected land use changes within Frederick County's "Urban Development Areas" (UDAs) and "Commercial Centers" (ComCntrs). Three future scenarios were created based on 25%, 50%, and 100% build-out within the UDAs and ComCntrs, and were named Future25, Future50, and Future100. A summary of the broad land use distributions for the entire Opequon Creek watershed for existing and the three future build-out scenarios is given in Table 1.9.

Table 1.9. Land Use Distribution for Existing and Future Scenarios[1]

Landuse Category	Existing	Future25	Future50	Future100
Agriculture	56.5%	53.3%	50.0%	43.6%
Urban	16.9%	22.1%	27.3%	37.7%
Forest	26.6%	24.6%	22.6%	18.6%

[1] Futurexx = Future land use distribution with xx% buildout within Frederick County's planned Urban Development Areas and Commercial Centers.

The 25% Buildout option (Future25) was selected as the most appropriate scenario as it more closely approximated growth conditions in the urbanizing Opequon Creek watershed.

1.7. TMDL Reductions and Allocations

TMDL allocation scenarios were developed by consolidating nonpoint source loads into 3 categories - agriculture, urban, and forestry - along with channel erosion, MS4, and point sources. The source category loads from the impaired watershed were then compared those of its area-adjusted TMDL reference watershed. Reductions were not required from source categories that contributed less than 1% of the total load. For stormwater permits, the same reductions were applied to both existing MS4 and "urban" source loads, but they are listed separately, since MS4 loads are required to be included in the WLA portion of the TMDL. In the WLA total, the contribution from MS4 areas was assumed to be equal to its existing sediment loads, since the modeled future increased load was assumed to be controlled through implementation of best management practices to reduce pollutants to the "maximum extent practicable," as called for by the MS4 regulations. Three alternative TMDL allocation scenarios were developed for each impaired watershed by taking varying percentages of reductions from the largest source categories with a variable load from agriculture for streambank stabilization needed to complement the reductions required from channel erosion. Note that each allocation scenario was designed to meet a target load equal to the TMDL minus the margin of safety (MOS).

1.7.1. Abrams Creek Allocations

The reductions required to meet the TMDL from existing and future conditions based on the 25% Buildout scenario will need to be made to the target modeling load, as summarized in Table 1.10 for Abrams Creek.

Table 1.10. Summary of Required Reductions for Abrams Creek

Load Summary	(t/yr)	Reductions Required (t/yr)	Reductions Required (% of Existing Load)
Projected Future Load	9,950	4,256	47.8%
Existing Load	8,907	3,213	36.1%
TMDL	6,327		
Target Modeling Load (TMDL-MOS)	5,695		

For Abrams Creek, "urban" and "channel erosion" were the largest categories from which reductions could be obtained as shown in Table 1.7. The recommended TMDL allocation scenario is Alternative 3, as it balances the probable greater cost of obtaining reductions from urban areas, with the probability of obtaining greater reductions from the largest source category - "channel erosion".

Table 1.11. TMDL Allocation Scenarios for Abrams Creek

Source Category	Future25 Abrams Creek (t/yr)	Abrams Creek TMDL Sediment Load Allocations					
		TMDL Alternative 1		TMDL Alternative 2		TMDL Alternative 3	
		(% reduction)	(t/yr)	(% reduction)	(t/yr)	(% reduction)	(t/yr)
Agriculture	1,269	**10%**	1,142	**10%**	1,142	**10%**	1,142
Urban	1,414	0%	1,414	**47.9%**	737	**25%**	1,061
Forestry	30	0%	30	0%	30	0%	30
Channel Erosion	6,620	**62.4%**	2,491	**47.9%**	3,451	**54.8%**	2,992
MS4*	590	0%	590	**47.9%**	308	**25%**	443
Point Sources	27	0%	27	0%	27	0%	27
Total	**9,950**		**5,695**		**5,695**		**5,695**

* Percent reductions in loads from MS4 areas were assumed equal to those from all Urban sources.

1.7.2. Lower Opequon Creek Allocations

The reductions required to meet the TMDL from existing and future conditions based on the 25% Buildout scenario will need to be made to the target modeling load, as summarized in Table 1.12 for Lower Opequon Creek.

Table 1.12. Summary of Required Reductions for Lower Opequon Creek

Load Summary	Opequon Creek (t/yr)	Reductions Required (t/yr)	Reductions Required (% of Existing Load)
Projected Future Load*	68,784	20,398	40.4%
Existing Load*	50,441	2,056	4.1%
TMDL	53,761		
Target Modeling Load (TMDL-MOS)	48,385		

* Opequon Creek loads reduced by upstream reductions called for in Abrams Creek TMDL.

Since the Abrams Creek watershed is part of the Lower Opequon Creek watershed, reductions in sediment load to the Abrams Creek TMDL allocation will also contribute to the reductions in the Lower Opequon Creek watershed. These reductions are accounted for in Table 1.13 by applying the ratio of the area-based delivery ratios (0.55) to the reductions called for in the Abrams Creek TMDL Alternative 3, and subtracting from the modeled Future25 loads in the Lower Opequon.

Table 1.13. Adjusting Lower Opequon Creek for Abrams TMDL Reductions (t/yr)

Source Category	Future25 Lower Opequon (t/yr)	Abrams Creek TMDL Reductions (t/yr)	Abrams Reductions Applied to Lower Opequon (t/yr)[1]	Future25 Lower Opequon - Abrams Reductions (t/yr)
Agriculture	13,232.0	126.9	70.3	13,161.8
Urban	4,210.9	353.6	195.8	4,015.1
Forestry	86.4	0.0	0.0	86.4
Channel Erosion	54,208.6	3,627.9	3,627.9	50,580.7
MS4	398.4	147.6	81.7	316.7
Point Sources	623.2	0.0	0.0	623.2
Total	**72,759.5**	**4,256.0**	**3,975.7**	**68,783.7**

[1] Abrams Creek TMDL Reductions * Lower Opequon sediment delivery ratio (0.0780) / Abrams Creek sediment delivery ratio (0.1409)

TMDL allocation scenarios were developed by consolidating nonpoint source loads into 3 categories - agriculture, urban, and forestry - and then comparing category loads from the Lower Opequon Creek watershed (minus Abrams Creek reductions) to those of its area-adjusted reference in Table 1.14. “Urban” and MS4 loads were generated as one land use category in the model, but they were separated during the spreadsheet post-processing, since MS4 loads are required to be included in the WLA portion of the TMDL. No reductions were required from forestry and point sources as each contributed <1% of the total load.

Table 1.14. Categorized Sediment Loads for Lower Opequon Creek (t/yr)

Source Category	Future25 Lower Opequon - Abrams Reductions (t/yr)	TMDL Target Area Adjusted Upper Opequon (t/yr)
Agriculture	13,161.8	15,075.9
Urban	4,015.1	3,167.2
Forestry	86.4	172.0
Channel Erosion	50,580.7	35,324.5
MS4	316.7	0.0
Point Sources	623.2	21.8
Total	**68,783.7**	**53,761.4**

Three alternative TMDL allocation scenarios were developed around the four remaining source categories, as shown in Table 1.16. The recommended TMDL allocation scenario is Alternative 3, as it balances the probable greater cost of obtaining reductions from urban areas, with the probability of obtaining greater reductions from the largest source category - "channel erosion".

Table 1.15. TMDL Allocation Scenarios for Lower Opequon Creek

Source Category	Future25 Lower Opequon - Abrams TMDL Reductions	Opequon Creek TMDL Sediment Load Allocations					
		TMDL Alternative 1		TMDL Alternative 2		TMDL Alternative 3	
		(% reduction)	(t/yr)	(% reduction)	(t/yr)	(% reduction)	(t/yr)
Agriculture	13,161.8	**10%**	11,845.6	**30.0%**	9,217.8	**15%**	11,187.5
Urban	4,015.1	0%	4,015.1	**30.0%**	2,812.0	**15%**	3,412.9
Forestry	86.4	0%	86.4	0%	86.4	0%	86.4
Channel Erosion	50,580.7	**37.7%**	31,498.4	**30.0%**	35,424.2	**35.1%**	32,806.2
MS4*	316.7	0%	316.7	**30.0%**	221.8	**15%**	269.2
Point Sources	623.2	0%	623.2	0%	623.2	0%	623.2
Total	**68,783.7**		**48,385.3**		**48,385.3**		**48,385.3**

* Percent reductions in loads from MS4 areas were assumed equal to those from all Urban sources.

1.8. Reasonable Assurance

Continued biological and chemical monitoring in the watershed by VADEQ, provisions of Virginia's WQMIRA legislation requiring implementation of developed TMDLs, MS4 regulations on storm sewer discharges, and the potential of funding through Section 319 and USDA's CREP and EQIP programs all provide the basis for a reasonable assurance that both of these TMDLs will be implemented.

1.9. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. The first public meeting for Abrams Creek was held on March 13, 2003, at Shenandoah University in Winchester, Virginia to inform the stakeholders about the TMDL study and presented information about both the benthic impairment and a concurrent bacteria impairment. Approximately 45 stakeholders attended this meeting. The public comment period ended on April 13, 2003.

The first public meeting for the benthic impairment in the Lower Opequon watershed was held on April 3, 2003, also at Shenandoah University, to inform the stakeholders of the benthic TMDL study on the Lower Opequon, as well as concurrent bacteria TMDL studies on both the Lower and Upper Opequon watersheds. Approximately 45 stakeholders attended this meeting. The public comment period for information shared at this meeting ended on May 3, 2003.

The final public meeting for both benthic impairments was held concurrently on July 1, 2003 at Shenandoah University to present a combined draft TMDL report and solicit comments from stakeholders. The public comment period ended on August 1, 2003. A summary of the questions and answers discussed at the meeting will be prepared and made available from the VADEQ Valley Regional Office in Harrisonburg, VA.

A glossary of terms used in the development of this TMDL is included in Appendix A.

CHAPTER 2: INTRODUCTION

2.1. Background

2.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

2.1.2. Impairment Listing

Stream segments on Abrams Creek (Segment ID: VAV-B09R_ABR01A00) and the Lower Opequon Creek (Segment ID: VAV-B09R_OPE01A00) are both listed as impaired on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998 and 2002) due to water quality violations of the General Standard (called a benthic impairment).

The Virginia Department of Environmental Quality (VADEQ) has delineated the benthic impairment on Abrams Creek on a stream length of 10.80 miles. The impaired stream segment begins at the Abrams Creek headwaters and continues downstream to its confluence with the Opequon River.

The Virginia Department of Environmental Quality (VADEQ) has delineated the benthic impairment on the Lower Opequon Creek on a stream length of 8.82 miles. The impaired stream segment begins at the confluence with Abrams Creek and continues downstream to the West Virginia state line.

2.1.3. Watershed Location and Description

The impaired stream segments both lie within the larger Opequon Creek watershed, which was considered in its entirety in order to estimate loads to the impaired segment of Lower Opequon Creek. A part of the Potomac and Shenandoah River basin, the Opequon Creek watershed is located in Frederick and Clarke Counties, Virginia, and encompasses the City of Winchester (Figure 2.1). The watershed is 36,321 ha (89,749 acres) in size. For discussion in this report, the Opequon Creek watershed has been sub-divided into 3 non-overlapping component areas – Abrams Creek watershed, Upper Opequon Creek watershed, and the Lower Opequon Remnant, as shown in Figure 2.2. The name - Lower Opequon Remnant – is used to avoid confusion with the state hydrologic unit B09 watershed, which is also called Lower Opequon Creek and includes the Abrams Creek watershed as well.

Abrams Creek watershed is located in Frederick County, Virginia, encompassing the majority of the City of Winchester. The watershed is 4,973 ha (12,278 acres) in size. Abrams Creek is mainly an urban watershed (50.7%) and is characterized by a rolling valley with the Little North Mountain (Appalachian) to the west and the Blue Ridge Mountains to the east. The remaining watershed area is divided between forest (21.9%) and agricultural (27.4%) land uses. Abrams Creek is a tributary of Opequon Creek, which in turn, is tributary to the Potomac River. The Potomac River then discharges into the Chesapeake Bay.

The Lower Opequon Remnant is located in both Frederick and Clarke Counties, Virginia, downstream from the confluence of the Upper Opequon Creek with Abrams Creek. This remnant is 16,405 ha (40,537 acres) in size. Lower Opequon Remnant is mainly an agricultural area (64.4%) with a small but increasing amount of urban and commercial uses (9.2%), and the remainder in forest. The area is also characterized by a rolling valley with the Appalachian Mountains to the west and the Blue Ridge Mountains to the east. Lower Opequon Creek is a tributary of the Potomac River, which in turn discharges into the Chesapeake Bay.

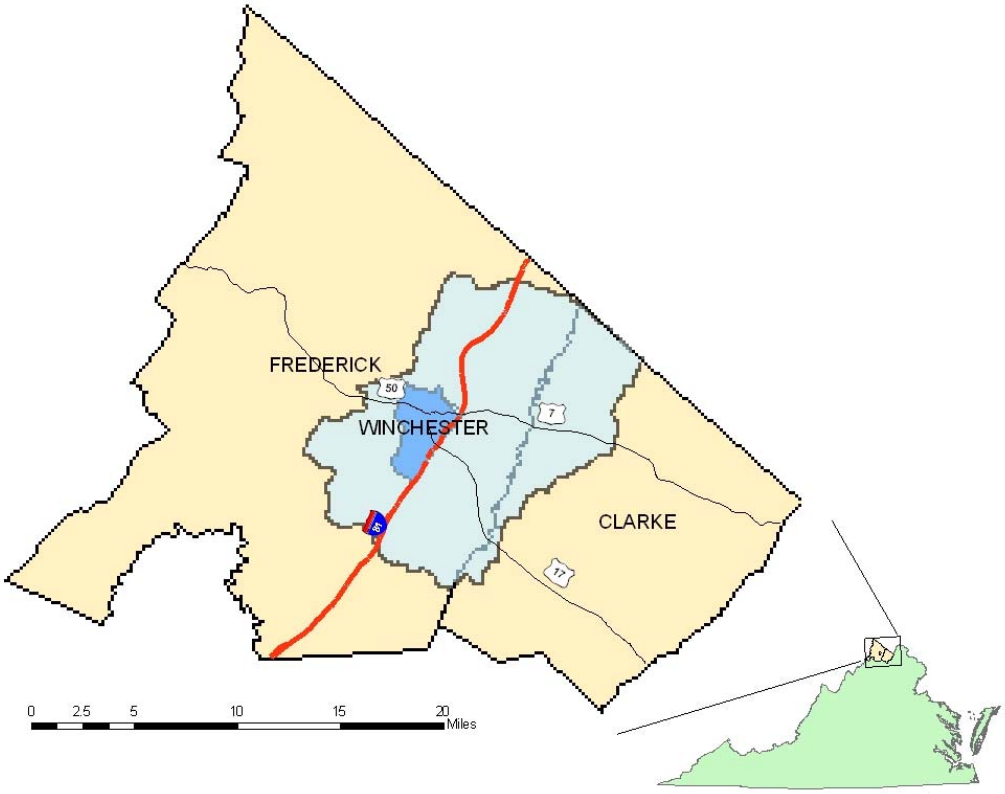

Figure 2.1. Location of the Opequon Creek watershed

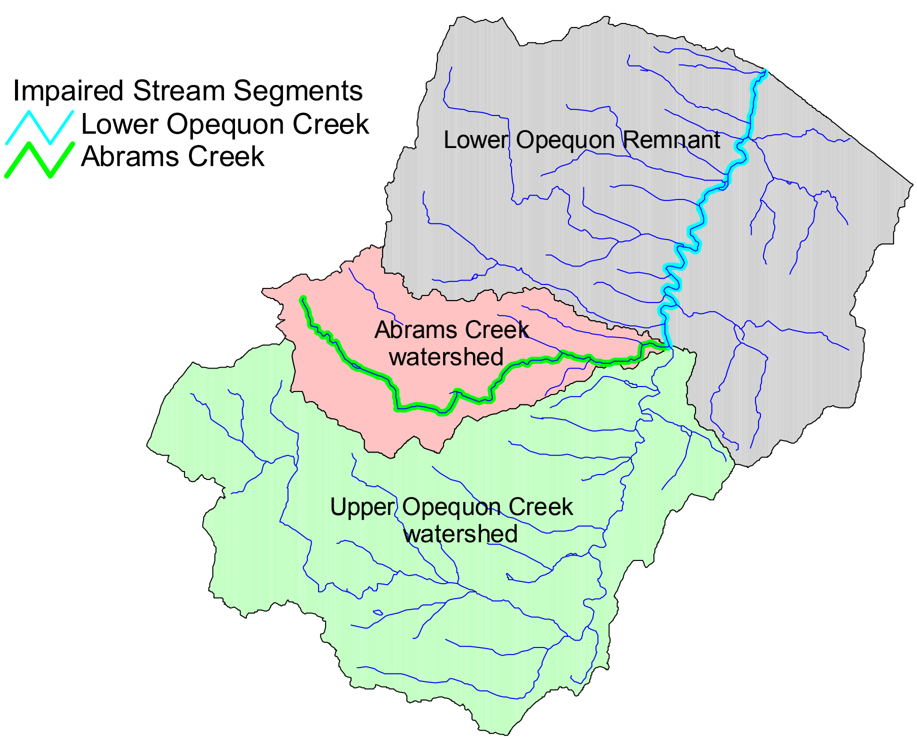

Figure 2.2. Opequon Creek Component Areas and Impaired Stream Segments

2.2. Designated Uses and Applicable Water Quality Standards

2.2.1. Designation of Uses (9 VAC 25-260-10)

> "All state waters are designated for the following uses: recreational uses (e.g. swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)". SWCB, 2003

Abrams Creek and the Lower Opequon Creek do not support the aquatic life designated uses due to violations of the general (benthic) standard described below.

2.2.2. General Standard (9 VAC 25-260-20)

The general standard for a water body in Virginia states:

> "All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.
>
> Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." SWCB, 2003

The biological monitoring program in Virginia used to evaluate compliance with the above standard is run by the Virginia Department of Environmental Quality (DEQ). Evaluations of monitoring data from this program focus on the benthic (bottom-dwelling) macro (large enough to see) invertebrates (insects, mollusks, crustaceans, and annelid worms) and are used to determine whether or not a stream segment is supporting the aquatic life use. Changes in water quality or available habitat generally result in alterations of the quantity and diversity of the benthic organisms that live in streams and other water bodies. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions. This is due to their relative immobility and their variable resistance to the diverse contaminants that are introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Qualitative and semi-quantitative biological monitoring have been conducted by DEQ since the early 1970's. The US EPA Rapid Bioassessment Protocol (RBP) II was employed beginning in the fall of 1990 to utilize standardized and repeatable methodology. For any single sample, the RBP produces ratings of the biological condition as “non-impaired,” “slightly impaired,” “moderately impaired,” and “severely impaired.” In Virginia, benthic samples are typically taken and analyzed twice a year in the spring and in the fall.

The RBP II procedure evaluates the benthic macroinvertebrate community by comparing ambient monitoring “network” stations to “reference” sites. A reference site is one that has been determined to be representative of a natural, unimpaired water body. The RBP II evaluation also accounts for the natural variation noted in streams in different ecoregions. One additional product of the RBP evaluation is a habitat assessment that measures the habitat suitability for the benthic community. Alterations in the quality of available habitat, in addition to water quality changes, may affect the abundance and diversity of the benthic community. Habitat alterations may result from excess erosion and sedimentation, scouring, hydrologic modifications, lack of riparian vegetation, or other causes.

Determination of the degree of support for the aquatic life designated use is based on conventional water column pollutants (DO, pH, temperature), sediment and nutrient screening value analyses, and biological monitoring data, as well as the best professional judgment of the regional biologist, relying mostly on the most recent data collected during the current 5-year assessment period. In Virginia, any stream segment with an overall rating of “moderately impaired” or “severely impaired” is placed on the state’s 303(d) list of impaired waters (VADEQ, 2002b).

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

3.1.1. Abrams Creek

The main branch of Abrams Creek runs for 10.80 miles from the headwaters to its confluence with Opequon Creek. Abrams Creek is perennial and has a trapezoidal channel cross-section. Town Run is a major tributary to Abrams Creek, flowing through the City of Winchester, where the channel has been hardened for most of its length. For the period of January 1980 through December 1988 (the hydrologic simulation calibration and validation period) at USGS gage 1616000 near the mouth of Abrams Creek, daily measured discharge ranged from 7.2 cubic feet per second (cfs) to 564 cfs, with a mean value of 26.6 cfs (USGS, 2003). Aquifers in this watershed are overlain by limestone (VWCB, 1985). Depth to the water table is generally in excess of 6 ft (SCS, 1982). Several springs contribute flow to Abrams Creeks, with the contributing area confined mainly to the topographic watershed boundaries.

3.1.2. Lower Opequon Creek

The main branch of Opequon Creek runs for 33.70 miles from the headwaters to the Virginia/West Virginia state line. Abrams Creek is tributary to Opequon Creek, and its confluence midway along the length of Opequon Creek serves as a convenient reference point. Opequon Creek is referred to as Upper Opequon Creek above the confluence (24.88 miles), and as Lower Opequon Creek below the confluence (8.82 miles). There are no stream flow gauging stations anywhere along the length of Lower Opequon Creek. Aquifers in this watershed are overlain by limestone (VWCB, 1985). Depth to the water table is in excess of 6 ft (SCS, 1982). The presence of numerous solution cavities and highly intense agricultural use result in a high potential for groundwater pollution (VWCB, 1985) from the surface.

3.2. Ecoregion

The Opequon Creek component areas are located in the Central Appalachian Ridge and Valley Level III Ecoregion. This ecoregion has numerous springs and caves. The ridges tend to be forested, while limestone valleys are composed of rich agricultural land (USEPA, 2002). These areas also share two level IV ecoregions - the Northern

Limestone/Dolomite Valleys and the Northern Shale Valleys. The Northern Limestone/Dolomite Valleys ecoregion has fertile land and is primarily agricultural. Steeper areas have scattered forests composed mainly of oak trees. Streams tend to flow year-round and have gentle slopes. The Northern Shale Valleys ecoregion has rolling valleys and low hills. The higher rate of soil erosion on this ecoregion causes increased turbidity in streams and a tendency toward stream impairment. This ecoregion is composed primarily of Appalachian Oak Forest or Oak-Hickory-Pine forest (Woods et al., 1999).

3.3. Soils and Geology

The main soils found in the Abrams Creek watershed and in the portion of the Opequon watershed that lies in Frederick County are the Weikert-Berks-Blairton and the Frederick-Poplimento-Oaklet associations (SCS, 1982a). The Weikert-Berks-Blairton (stony silt loam) soils are gently sloping to moderately steep, shallow and moderately deep, well drained soils with a medium or fine textured subsoil, formed from weathered shale or sandstone. These soils are on broad, smooth or slightly convex uplands and in broad areas dissected by shallow drainageways (SCS, 1982a). The Frederick-Poplimento-Oaklet (loam) soils are gently sloping to very steep well-drained soils with fine textured subsoil. They are formed from weathered limestone. These soils are on gently sloping to moderately steep narrow to broad valley uplands dissected by some drainageways (SCS, 1982a).

The main soils found in the portion of the Opequon Creek watershed that lies in Clarke County are the Berks-Endcav-Weikert, Carbo-Opequon-Oaklet, Rock outcrop-Opequon Swimley, and Rock outcrop-Hagertown-Swimley associations (SCS, 1982b). The Berks-Endcav-Weikert (silty clay loam) soils are shallow to deep, well-drained soils that have a loamy or clayey subsoil and formed in materials weathered from shale or calcareous shale on uplands (SCS, 1982b). The Carbo-Opequon-Oaklet (silty clay loam) soils are also shallow to deep, well-drained soils that have a clayey subsoil and formed in materials weathered from limestone on uplands (SCS, 1982b). The Rock outcrop-Opequon Swimley and Rock outcrop-Hagertown-Swimley (silt loam) soils are shallow to deep, well-drained soils with clayey subsoil and are formed in materials weathered from limestone on uplands. Areas of rock outcrop are comprised mainly of limestone and some dolomite (SCS, 1982b).

3.4. Climate

The climate of Abrams Creek and Opequon Creek watersheds is defined through meteorological observations made by the National Weather Service's cooperative observer in Winchester (Coop ID# 449181). The weather station is located within the Abrams Creek watershed. Average annual precipitation is 38.29 in. with 56% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2002). Average annual snowfall is 22.5 in. with the highest snowfall occurring during January (SERCC, 2002). Average annual daily temperature is 53.7°F. The highest average daily temperature of 74.9°F occurs in July while the lowest average daily temperature of 31.9°F occurs in January (SERCC, 2002).

3.5. Existing Land Use

The broad distribution of existing land uses in the three component areas of the Opequon Creek watershed are shown in Figure 3.1, and described in more detail in the following sub-sections.

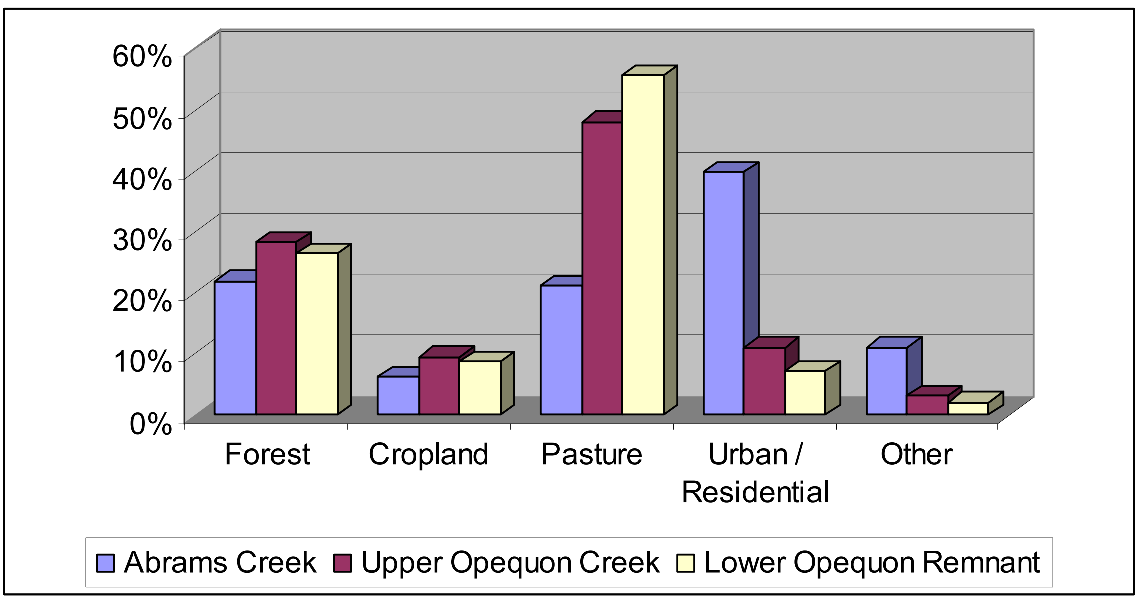

Figure 3.1. Land Use Distribution in the Opequon Creek Watershed

3.5.1. Abrams Creek Land Use

Residential developments comprise the main land use category in the Abrams Creek watershed, covering 23% of the total watershed area. Other urban developments (commercial, industrial, and transportation, for example) cover 17% of the watershed, while urban grass and transitional areas account for another 11%. These urban land uses are concentrated in the City of Winchester, which stretches north-south across the middle of the watershed. The non-urban land uses are located primarily in the western and eastern portions of the watershed, outside the Winchester city limits. Forest, pasture, cropland, and orchards account for 22%, 21%, 1%, and 5% of the watershed area, respectively. Detailed land use information is provided in chapter 6.

3.5.2. Upper Opequon Creek Land Use

Agriculture comprises the main land use category in the Upper Opequon watershed, covering 57% of the total watershed area. Pasture covers 48%, cropland accounts for about 5%, and orchards 4% of the watershed area. Forest acreage accounts for about 28% of the total area. Urban land uses cover about 14.2% of the Upper Opequon Creek watershed. The Upper Opequon Creek watershed includes a small portion of the City of Winchester on its southern side. The urban land uses in the Upper Opequon Creek watershed are concentrated in and to the south and east of the City of Winchester. Detailed land use information is provided in chapter 6.

3.5.3. Lower Opequon Remnant Land Use

Agriculture comprises the main land use category in the Lower Opequon Remnant, covering 64% of the total watershed area. Pasture covers 55%, cropland accounts for about 6%, and orchards 3% of the watershed area. Forest acreage accounts for about 26% of the total area. Urban land uses cover about 9.2% of the Lower Opequon. The Lower Opequon Remnant includes a small northern portion of the City of Winchester. The urban land uses in the Lower Opequon Remnant are concentrated in and to the north of the City of Winchester. Detailed land use information is provided in chapter 6.

3.6. Future Land Use

The Opequon Creek watershed is experiencing urban development and growth, so changes in land use must be estimated for modeling future loads as part of the TMDL allocation procedure. Future land use scenarios were created based on the following assumptions:

- Future urban development would occur within Frederick County's "Urban Development Areas" (UDAs) and "Commercial Centers" (ComCntrs).
- Agricultural and forestry land uses within these areas would potentially decrease to 0% under full buildout.
- Water, transitional, and urban greenspace areas would not change.

- Commercial and residential land uses within these areas would increase in proportion to their existing ratios.

The Opequon Creek component areas were used for this analysis, as shown in Figure 3.2. The land use summaries were generated, and the redistribution for future scenarios was performed, independently within each of these areas. Three future scenarios were then created based on 25%, 50%, and 100% build-out within the UDAs and ComCntrs shown in Figure 3.2, and were named Future25, Future50, and Future100.

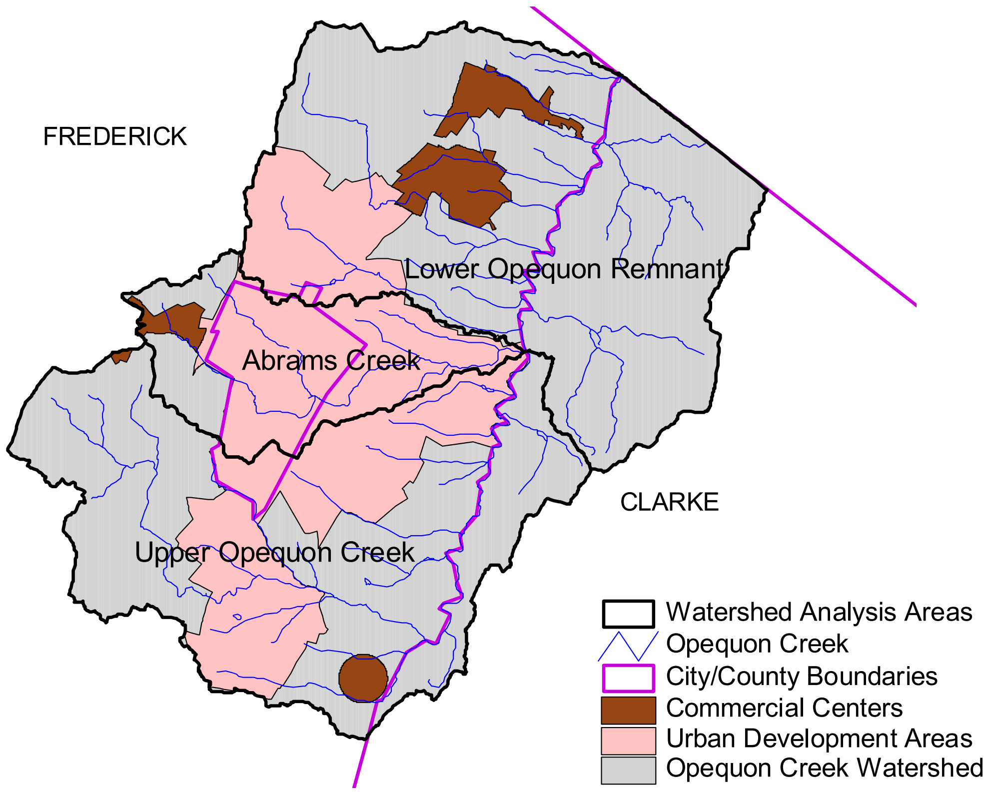

Figure 3.2. Areas Subject to Future Development – Opequon Creek Watershed

The area encompassed by the UDAs and ComCntrs is approximately 12,475 ha, or 34% of the entire watershed. Of that area, 4,950 ha is already in commercial or residential use, or is not subject to change, leaving a maximum area of 7,525 ha (21%) subject to change during the 100% build-out scenario. A summary of the broad land use distributions for the entire Opequon Creek watershed for existing and the three future build-out scenarios is given in Table 3.1. Spreadsheets showing the detailed development of the alternative future scenarios are included in Appendix B.

Table 3.1. Land Use Distribution for Existing and Future Scenarios[1]

Landuse Category	Existing	Future25	Future50	Future100
Agriculture	56.5%	53.3%	50.0%	43.6%
Urban	16.9%	22.1%	27.3%	37.7%
Forest	26.6%	24.6%	22.6%	18.6%

[1] Futurexx = Future land use distribution with xx% buildout within Frederick County's planned Urban Development Areas and Commercial Centers.

3.7. Water Quality Data

Virginia DEQ monitored chemical water quality in Abrams Creek on a monthly basis from August 1976 through the present at station ABR000.78, located 0.2 miles above the Rt. 7 bridge, near its confluence with Opequon Creek. The Lower Opequon was monitored from April 1979 through June 2001 at station OPE029.61, located at the Rt. 672 bridge, approximately 6 miles upstream from the state line. The ambient water quality data used in this study are included under the stressor analysis section (chapter 4) of this report.

3.8. Biological Monitoring Data

Biological monitoring performed in Virginia follows EPA's Rapid Bioassessment Protocol II (RBP II), which involves enumeration of a number of measurements, or metrics, of the benthic macro-invertebrate population (Barbour et al., 1999). The RBP II is used to assess compliance with the general standard in Virginia. This protocol compares the conditions of a target stream to those of an unimpaired stream, whose drainage area is called the reference watershed. Sampling is usually conducted biannually in the spring and in the fall, and is accompanied with a qualitative habitat evaluation of the stream corridor in the vicinity of the biological monitoring site.

The Macroinvertebrate Aggregated Index for Streams (MAIS) is a secondary index whose metrics are also calculated by VADEQ, but this index is only used as a supplemental indicator of stream quality (Smith and Voshell, 1997). Individual MAIS metrics are rated against a fixed scale rather than against those of a reference watershed, as in the RBP II index.

Virginia DEQ, with assistance from USEPA Region 3, is in the middle of a process to upgrade its biomonitoring and biological assessment methods to those currently recommended in the mid-Atlantic region. As part of this effort, a study has been performed to assist the agency to move from a paired-reference site approach to a regional reference condition approach, and has led to the development of a proposed stream condition index (SCI) for Virginia's non-coastal areas (Tetra Tech, 2002b). This multimetric index is based on 8 biomonitoring metrics and has a scoring range of 0 – 100. The maximum score of 100 represents the best benthic community sites. Current proposed threshold criteria would define "unimpaired" sites as those with an SCI > 61.9 (the 10th percentile of all scores from 62 reference sites in Virginia), and "impaired" sites as those with an SCI < 56.3 (the 5th percentile).

3.8.1. Abrams Creek Data

The VADEQ biological monitoring station on Abrams Creek - station ABR000.78 – is located near the confluence with Opequon Creek, and is the same site used for VADEQ's monthly ambient water quality measurements. Strait Creek, in Highland County, was used as the RBP II reference watershed for Abrams Creek. All 7 of the benthic assessments performed between October 1994 and October 2001 received a rating of "moderately impaired", as shown in Table 3.2.

Ratings of moderately impaired resulted in Abrams Creek being listed as not supporting of the Aquatic Life designated use in both the 1998 and the 2002 303(d) impaired waters list. VADEQ listed nonpoint source urban runoff as the probable cause of the benthic impairment (VADEQ, 1998 and 2002).

The MAIS metrics for Abrams Creek along with their scores and final ratings are given for each sample in Table 3.3.

Current proposed threshold criteria would define "unimpaired" sites as those with an SCI > 61.9 (the 10th percentile of all scores from 62 reference sites in Virginia), and "impaired" sites as those with an SCI < 56.3 (the 5th percentile). The average SCI score for Abrams Creek, shown in Table 3.4, is consistent with that of an "impaired" site, and average SCI score for Strait Creek, it's biological reference watershed, is consistent with those of "unimpaired" sites.

The habitat assessment parameters and scores for Abrams Creek are listed in Table 3.5. The range of scores for each of the 10 habitat assessment parameters is 0-20. A minimum score of 0 indicates the poorest habitat conditions, while a maximum score of 20 indicates the most desirable conditions.

Table 3.2. RBP II Scores for Abrams Creek (ABR000.78)

RBP II	(Scores calculated against a reference watershed.)					**ABR000.78**	
Sample Date	10/17/94	10/9/98	5/10/99	10/20/99	4/12/00	10/17/00	10/10/01	Average
a. RBP II Metric Values								
Taxa Richness	11	13	19	12	11	13	9	12.57
MFBI	4.96	5.13	5.67	5.15	5.10	5.06	5.43	5.22
SC/CF	0.00	0.00	0.13	0.04	2.00	0.08	0.00	0.32
EPT/Chi Abund	2.19	18.83	0.38	0.74	0.18	2.91	2.29	3.93
% Dominant	20.75	55.77	46.90	32.41	46.36	32.14	42.96	39.61
Dominant Species	Hydropsychidae	Hydropsychidae	Chironomidae (A)	Chironomidae (A)	Chironomidae (A)	Hydropsychidae	Hydropsychidae	
EPT Index	4	3	6	4	4	6	4	4.43
Comm. Loss Index	1.09	0.85	0.53	1.00	1.00	0.69	1.00	0.88
SH/Tot	0.06	0.03	0.01	0.18	0.01	0.03	0.00	0.04
Abundance	106	156	113	108	110	112	142	121
b. Reference Metric Values								
Station_ID	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27	
Reference Sample Date	10/11/94	10/28/98	5/17/99	10/13/99	5/4/00	10/13/00	10/15/01	Average
Taxa Richness	20	19	18	21	20	19	15	18.86
MFBI	3.47	3.18	3.79	3.64	4.15	3.61	3.77	3.66
SC/CF	0.59	0.23	1.70	2.21	0.78	1.56	1.77	1.26
EPT/Chi Abund	55.00	36.50	4.87	29.00	3.80	20.00	35.00	26.31
% Dominant	25.28	21.84	20.66	25.23	16.00	25.23	24.11	22.62
EPT Index	9	13	11	10	12	12	9	10.86
Comm. Loss Index	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
SH/Tot	0.02	0.28	0.17	0.15	0.11	0.05	0.04	0.12
Abundance	178	174	121	111	125	111	141	137
Reference Biological Score	46	46	46	46	48	46	46	46.29
c. RBP II Metric Ratios								
Taxa Richness	55.0	68.4	105.6	57.1	55.0	68.4	60.0	67.08
MFBI	70.0	62.0	66.7	70.7	81.4	71.4	69.5	70.24
SC/CF	0.0	0.0	7.4	1.7	255.6	5.4	0.0	38.58
EPT/Chi Abund	4.0	51.6	7.8	2.6	4.6	14.5	6.5	13.09
% Dominant	20.8	55.8	46.9	32.4	46.4	32.1	43.0	39.61
EPT Index	44.4	23.1	54.5	40.0	33.3	50.0	44.4	41.41
Comm. Loss Index	1.09	0.85	0.53	1.00	1.00	0.69	1.00	0.88
SH/Tot	251.9	9.3	5.4	114.9	8.1	49.6	0.0	62.73
d. RBP II Metric Scores								
Taxa Richness	2	4	6	2	2	4	2	3.1
MFBI	2	2	2	4	4	4	2	2.9
SC/CF	0	0	0	0	6	0	0	0.9
EPT/Chi Abund	0	4	0	0	0	0	0	0.6
% Dominant	4	0	0	2	0	2	0	1.1
EPT Index	0	0	0	0	0	0	0	0.0
Comm. Loss Index	4	4	4	4	4	4	4	4.0
SH/Tot	6	0	0	6	0	4	0	2.3
Total RBP II Score	18	14	12	18	16	18	8	14.9
% of Reference	39.13	30.43	26.09	39.13	33.33	39.13	17.39	32.1
RBP II Assessment	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	

Table 3.3. MAIS Assessment Results for Abrams Creek

a. MAIS Metric Values	the best conditions are shown at the far right.)								Best Score
Sample Date	10/17/94	10/9/98	5/10/99	10/20/99	4/12/00	10/17/00	10/10/01	Average	Category
% 5 Dominant	84.91	89.74	84.96	95.37	95.45	87.50	92.96	90.1	<79.13
MFBI	4.96	5.13	5.67	5.15	5.10	5.06	5.43	5.2	<4.22
% Haptobenthos	55.66	85.26	36.28	40.74	48.18	70.54	66.20	57.6	>83.26
EPT Index	4.00	3.00	6.00	4.00	4.00	6.00	4.00	4.4	>7
# Mayfly Taxa	2.00	1.00	4.00	2.00	2.00	4.00	2.00	2.4	>3
% Mayfly Abundance	4.72	1.28	4.42	1.85	6.36	7.14	3.52	4.2	>17.52
Simpson's Diversity Index	0.85	0.65	0.74	0.80	0.63	0.81	0.72	0.7	>0.823
# Intolerant Taxa	6.00	7.00	7.00	5.00	6.00	7.00	4.00	6.0	>9
% Scraper Abundance	0.00	0.00	0.88	0.93	3.64	4.46	0.00	1.4	>10.7
b. MAIS Scores									
% 5 Dominant	1	1	1	1	1	1	1	1.0	
MFBI	1	1	0	1	1	1	1	0.9	
% Haptobenthos	1	2	0	0	0	1	1	0.7	
EPT Index	1	1	1	1	1	1	1	1.0	
# Mayfly Taxa	1	1	2	1	1	2	1	1.3	
% Mayfly Abundance	1	1	1	1	1	1	1	1.0	
Simpson's Diversity Index	2	0	1	1	0	1	1	0.9	
# Intolerant Taxa	1	1	1	1	1	1	1	1.0	
% Scraper Abundance	0	0	1	1	1	1	0	0.6	
Total MAIS Score	9	8	8	8	7	10	8	8.3	**18**
MAIS Assessment	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**		**Best**

Table 3.4. Stream Condition Index Statistics for Abrams Creek

Station ID	Stream	No. of Samples	Stream Condition Index		
			Minimum	Maximum	Average
TMDL Station					
ABR000.78	Abrams Creek	7	39.4	53.3	45.4
Biological Reference Stations					
STC004.27	Strait Creek	7	75.0	82.2	78.6

Table 3.5. Habitat Evaluation Scores for Abrams Creek

Habitat Evaluation Date	10/17/94	10/9/98	5/10/99	10/20/99	4/12/00	10/17/00	10/10/01	
HabSampID	ABR32	ABR1147	ABR1234	ABR2413	ABR2464	ABR2524	ABR2599	Average
ALTER	16	15	13	14	13	15	13	14.1
BANKS	12	11	17	17	13	12	14	13.7
BANKVEG	8	9	7	11	7	9	9	8.6
EMBED	10	18	12	9	19	11	5	12.0
FLOW	18	18	19	19	18	20	17	18.4
RIFFLES	12	13	18	20	18	20	18	17.0
RIPVEG	0	7	2	5	3	2	2	3.0
SEDIMENT	12	17	14	18	18	17	17	16.1
SUBSTRATE	10	18	17	15	16	14	15	15.0
VELOCITY	14	15	14	17	15	16	18	15.6
Total Habitat Score	112	141	133	145	140	136	128	133.6

*ALTER = channel alterations; BANKS = bank stability; BANKVEG = bank vegetation; EMBED = embeddedness; FLOW = flow quantity; RIFFLES = presence of riffles; RIPVEG = riparian vegetation; SEDIMENT = abundance of bottom sediment; SUBSTRATE = availability of firm, clean stream bottom surfaces; VELOCITY = velocity of flow.

3.8.2. Lower Opequon Data

The VADEQ biological monitoring station on the Lower Opequon Creek - station OPE029.61 - is located 6.05 miles upstream from the state line, only 2.77 miles below the confluence with Abrams Creek, and does not correspond with one of VADEQ's monthly ambient water quality stations. Four different watersheds were used as references for the Lower Opequon Creek at various times. In fall 1994, Jackson River was used as the reference watershed. In spring 1995, Stony Creek was used as the reference watershed. In fall 1998 and spring 1999, Bullpasture River was used as the reference watershed. In fall 1999, Smith Creek was used as the reference watershed. Finally, Cowpasture River has been used as the reference for all samples since spring 2000. Of the nine assessments performed between fall 1994 and spring 2002, 7 received a rating of "moderately impaired", as shown in Table 3.6. Ratings of moderately impaired resulted in Lower Opequon Creek being listed as not supporting of the Aquatic Life designated use in both the 1998 and the 2002 303(d) impaired waters list. VADEQ listed urban nonpoint sources as the probable cause of the benthic impairment (VADEQ, 1998).

The MAIS metrics for the Lower Opequon Creek along with their scores and final ratings are given for each sample in Table 3.7.

Current proposed threshold criteria would define "unimpaired" sites as those with an SCI > 61.9 (the 10th percentile of all scores from 62 reference sites in Virginia), and "impaired" sites as those with an SCI < 56.3 (the 5th percentile). The average SCI score for Lower Opequon Creek, shown in Table 3.8, is consistent with that of an "impaired" site, and average SCI scores for Jackson River, Stony Creek, Bullpasture River, Smith Creek, and Cowpasture River, the various watersheds used for biological references, are consistent with those of "unimpaired" sites.

The habitat assessment parameters and scores for the Lower Opequon Creek are listed in Table 3.9. The range of scores for each of the 10 habitat assessment parameters is 0-20. A minimum score of 0 indicates the poorest habitat conditions, while a maximum score of 20 indicates the most desirable conditions.

Table 3.6. RBP II Scores for Lower Opequon Creek (OPE029.61)

RBP II (Scores calculated against a reference watershed.) **OPE029.61**

Sample Date	10/19/94	5/3/95	10/9/98	5/10/99	10/20/99	4/12/00	10/17/00	10/10/01	10/10/01	5/28/02	Average
a. RBP II Metric Values											
Taxa Richness	13	15	13	17	12	9	12	12	12	11	12.56
MFBI	5.00	4.81	5.26	5.11	4.19	6.15	4.89	5.10	5.10	5.05	5.07
SC/CF	0.22	0.52	0.22	1.40	19.00	0.00	0.50	0.12	0.12	4.33	2.91
EPT/Chi Abund	7.00	1.87	23.67	0.64	14.00	0.15	1.50	0.91	0.91	0.65	4.92
% Dominant	26.42	28.29	44.07	43.27	52.83	54.79	42.86	33.80	33.80	36.09	41.09
Dominant Species	Elmidae	Ephemerellid	Hydropsychid	Chironomida	Elmidae	Chironomida	Elmidae	Elmidae	Chironomida	Chironomidae	
EPT Index	6	6	4	6	3	3	4	6	6	5	4.78
Comm. Loss Index	1.31	0.93	0.62	0.53	0.58	1.33	0.67	0.50	0.50	1.00	0.74
SH/Tot	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.01
Abundance	106	152	106	106	106	146	106	106	106	106	116
b. Reference Metric Values											
Station_ID	JKS067.00	STY006.73	BLP000.79	BLP000.79	SMT006.62	CWP050.66	CWP050.66	CWP050.66	CWP050.66	CWP050.66a	
Reference Sample Date	10/24/94	5/9/95	10/7/98	5/13/99	10/14/99	5/3/00	10/12/00	10/13/01	10/13/01	5/6/02	Average
Taxa Richness	25	26	15	19	16	18	14	14	14	17	17.00
MFBI	3.27	3.77	4.25	4.33	4.17	4.06	3.65	3.84	3.84	3.94	3.98
SC/CF	0.84	1.88	2.04	1.26	1.04	4.11	1.15	1.26	1.26	9.00	2.56
EPT/Chi Abund	13.40	6.38	24.00	1.97	9.00	6.71	84.00	11.67	11.67	6.43	17.98
% Dominant	21.13	11.19	42.00	29.41	36.89	38.73	30.36	23.53	23.53	44.70	31.15
EPT Index	11	13	9	10	8	8	9	8	8	9	9.11
Comm. Loss Index	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
SH/Tot	0.18	0.04	0.02	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Abundance	142	134	142	142	142	142	142	142	142	142	141
Reference Biological Score	46	48	42	46	44	44	44	46	46	42	44.67
c. RBP II Metric Ratios											
Taxa Richness	52.0	57.7	86.7	89.5	75.0	50.0	85.7	85.7	85.7	64.7	75.63
MFBI	65.5	78.4	80.8	84.9	99.6	66.1	74.6	75.4	75.4	78.0	79.22
SC/CF	25.8	27.7	10.9	110.8	1832.1	0.0	43.5	9.1	9.1	48.1	232.38
EPT/Chi Abund	52.2	29.3	98.6	32.8	155.6	2.2	1.8	7.8	7.8	10.0	38.43
% Dominant	26.4	28.3	44.1	43.3	52.8	54.8	42.9	33.8	33.8	36.1	41.09
EPT Index	54.5	46.2	44.4	60.0	37.5	37.5	44.4	75.0	75.0	55.6	52.84
Comm. Loss Index	1.31	0.93	0.62	0.53	0.58	1.33	0.67	0.50	0.50	1.00	0.74
SH/Tot	0.0	14.7	84.7	19.6	115.1	0.0	0.0	140.8	140.8	0.0	57.32
d. RBP II Metric Scores											
Taxa Richness	2	2	6	6	4	2	6	6	6	4	4.7
MFBI	2	4	4	4	6	2	4	4	4	4	4.0
SC/CF	2	2	0	6	6	0	4	0	0	4	2.4
EPT/Chi Abund	4	2	6	2	6	0	0	0	0	0	1.8
% Dominant	4	4	0	0	0	0	0	2	2	2	1.1
EPT Index	0	0	0	0	0	0	0	2	2	0	0.4
Comm. Loss Index	4	4	4	4	4	4	4	4	4	4	4.0
SH/Tot	0	0	6	0	6	0	0	6	6	0	2.7
Total RBP II Score	18	18	26	22	32	8	18	24	24	18	21.1
% of Reference	39.13	37.50	61.90	47.83	72.73	18.18	40.91	52.17	52.17	42.86	47.4
RBP II Assessment	**Moderate**	**Moderate**	**Slight**	**Moderate**	**Slight**	**est judgeme**	**Moderate**	**est judgeme**	**Moderate**	**Moderate**	

Table 3.7. MAIS Assessment Results for Lower Opequon Creek

MAIS (Scores calculated against a fixed scale. Values indicating the best conditions are shown at the far right.)

a. MAIS Metric Values												**Best Score**
Sample Date	10/19/94	5/3/95	10/9/98	5/10/99	10/20/99	4/12/00	10/17/00	10/10/01	10/10/01	5/28/02	Average	**Category**
% 5 Dominant	91.51	80.92	87.29	85.58	93.40	96.58	89.29	91.55	91.55	83.46	88.84	<79.13
MFBI	5.00	4.81	5.26	5.11	4.19	6.15	4.89	5.10	5.10	5.05	5.07	<4.22
% Haptobenthos	59.43	67.76	85.59	39.42	90.57	21.23	75.00	59.86	59.86	45.11	60.49	>83.26
EPT Index	6.00	6.00	4.00	6.00	3.00	3.00	4.00	6.00	6.00	5.00	4.78	>7
# Mayfly Taxa	5.00	4.00	3.00	4.00	3.00	2.00	3.00	5.00	5.00	4.00	3.67	>3
% Mayfly Abundance	27.36	39.47	16.10	24.04	13.21	7.53	8.93	12.68	12.68	21.80	17.38	>17.52
Simpson's Diversity Index	0.83	0.83	0.74	0.77	0.65	0.64	0.76	0.76	0.76	0.78	0.75	>0.823
# Intolerant Taxa	7.00	10.00	6.00	9.00	7.00	3.00	6.00	8.00	8.00	7.00	7.11	>9
% Scraper Abundance	7.55	9.21	10.17	6.73	35.85	0.00	8.93	2.11	2.11	9.77	9.43	>10.7
b. MAIS Scores												
% 5 Dominant	1	1	1	1	1	1	1	1	1	1	1.0	
MFBI	1	1	1	1	2	0	1	1	1	1	1.0	
% Haptobenthos	1	1	2	0	2	0	1	1	1	0	0.9	
EPT Index	1	1	1	1	1	1	1	1	1	1	1.0	
# Mayfly Taxa	2	2	1	2	1	1	1	2	2	2	1.6	
% Mayfly Abundance	2	2	1	2	1	1	1	1	1	2	1.3	
Simpson's Diversity Index	2	2	1	1	0	0	1	1	1	1	0.9	
# Intolerant Taxa	1	2	1	1	1	1	1	1	1	1	1.1	
% Scraper Abundance	1	1	1	1	2	0	1	1	1	1	1.0	
Total MAIS Score	12	13	10	10	11	5	9	10	10	10	9.8	**18**
MAIS Assessment	**Poor**	**Good**	**Poor**	**Poor**	**Poor**	**Very Poor**	**Poor**	**Poor**	**Poor**	**Poor**		**Best**

Table 3.8. Stream Condition Index Statistics for Lower Opequon Creek

Station ID	Stream	No. of Samples	Stream Condition Index		
			Minimum	Maximum	Average
TMDL Station					
OPE029.61	Lower Opequon Creek	10	28.9	56.3	49.0
Biological Reference Stations					
JKS067.00	Jackson River	1	78.6	78.6	78.6
STY006.81	Stony Creek	1	84.4	84.4	84.4
SMT006.62	Smith Creek	1	67.9	67.9	67.9
BLP000.79	Bullpasture Creek	2	69.4	73.5	71.5
CWP050.66	Cowpasture Creek	5	70.5	79.8	74.7

Table 3.9. Habitat Evaluation Scores for Lower Opequon Creek

Habitat Evaluation Date	10/19/94	5/3/95	10/9/98	5/10/99	10/20/99	4/12/00	10/17/00	10/10/01	5/28/02	
HabSampID	OPE56	OPE237	OPE1161	OPE1235	OPE2441	OPE2501	OPE2559	OPE2630	OPE2660	Average
ALTER	16	16	13	14	19	19	19	19	18	17.1
BANKS	10	12	12	12	12	16	12	14	16	13.3
BANKVEG	10	10	16	17	14	19	20	20	18	16.8
EMBED	8	6	3	11	12	6	2	4	8	6.5
FLOW	18	20	17	16	20	19	18	14	18	17.8
RIFFLES	12	10	2	16	5	10	16	3	3	8.1
RIPVEG	8	6	12	16	12	7	7	12	11	10.4
SEDIMENT	10	10	15	17	17	15	10	12	14	13.8
SUBSTRATE	12	6	7	10	16	5	7	6	10	8.4
VELOCITY	14	10	7	13	16	16	16	16	16	13.8
Total Habitat Score	118	106	104	142	143	132	127	120	132	125.8

*ALTER = channel alterations; BANKS = bank stability; BANKVEG = bank vegetation; EMBED = embeddedness; FLOW = flow quantity; RIFFLES = presence of riffles; RIPVEG = riparian vegetation; SEDIMENT = abundance of bottom sediment; SUBSTRATE = availability of firm, clean stream bottom surfaces; VELOCITY = velocity of flow.

CHAPTER 4: BENTHIC STRESSOR ANALYSIS

4.1. Introduction

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on physical or chemical water quality parameters, the pollutant is not implicitly identified in the assessment, as it is with physical or chemical parameters. The process outlined in EPA's *Stressor Identification Guidance Document* (EPA, 2000) was used to separately identify the most probable stressor(s) for Abrams Creek and for Lower Opequon Creek. A list of candidate causes was developed from published literature and stakeholder input. Chemical and physical monitoring data provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible. Volunteer monitoring data, land use distribution, and visual assessment of conditions in and along the stream corridor provided additional information to support or refute the candidacy of specific potential stressors. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The common candidate benthic stressors that were assessed were sediment, organic matter, pH, toxics, nutrients, and temperature. Each of these is considered in the following sections, first for Abrams Creek, and then for the Lower Opequon Creek.

The results of the stressor analysis for each impaired watershed are divided into the following three categories:

- Non-Stressors: Those stressors with data indicating normal conditions, or without violations of a governing standard, or without observable impacts usually associated with a specific stressor, were eliminated as possible stressors.

- Possible Stressors: Those stressors with data indicating possible links, but with inconclusive data, were considered to be possible stressors.

- Most Probable Stressor: The stressor with the most consistent data linking it with the poorer benthic metrics, was considered to be the most probable stressor.

4.2. Abrams Creek Stressor Analysis

4.2.1. Non-Stressors

Temperature

Although the habitat evaluation indicated sparse riparian vegetation along the reach where biological monitoring occurred (see Table 3.3), the reduction in vegetation appeared not to affect stream water temperature, which has fluctuated within normal bounds during the 22 years of monitored data and has never exceeded Virginia's maximum water quality standard of 31°C for Class IV waters, as shown in Figure 4.1. Temperature, therefore, does not appear to be a stressor.

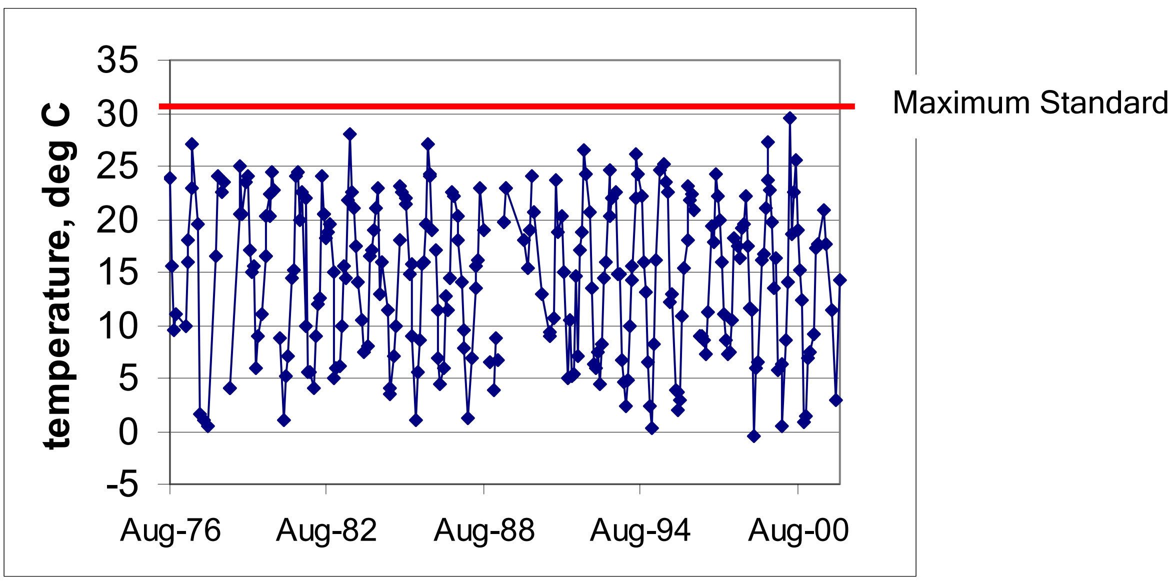

Figure 4.1. Water Temperature in Abrams Creek

pH

All pH values fall between the minimum standard of 6 and the maximum standard of 9 (Figure 4.2). Alkalinity concentrations, which may reflect influences and/or effects of pH, also appear fairly constant and within a normal range of 30-500 mg/L for areas within the Northern Appalachian Ridges and Valley physiographic region (Figure 4.3). Therefore, pH is not considered to be a stressor on the Abrams Creek benthic community.

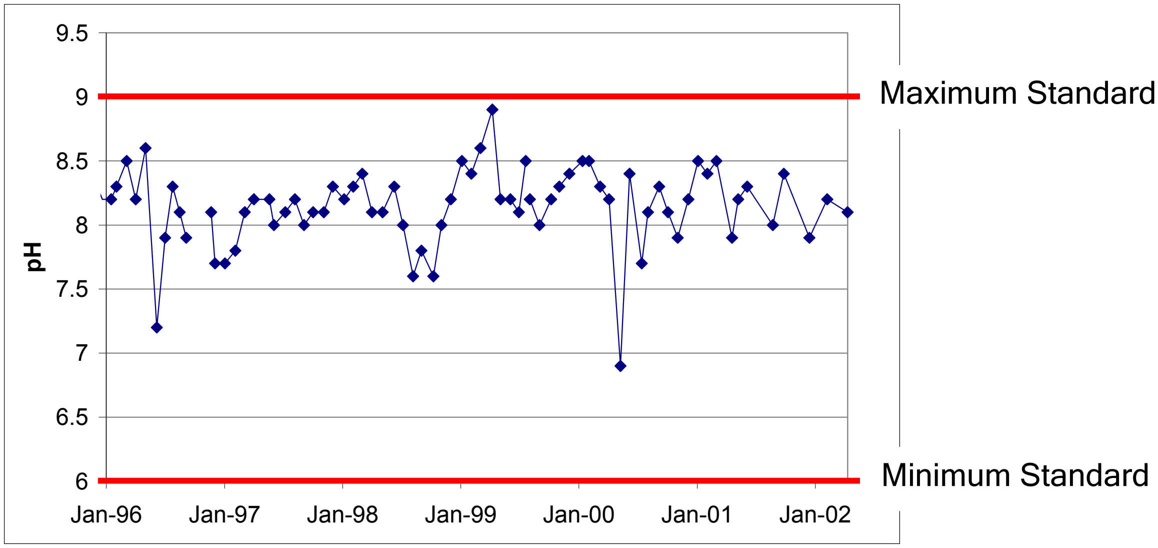

Figure 4.2. Field pH Data for Abrams Creek

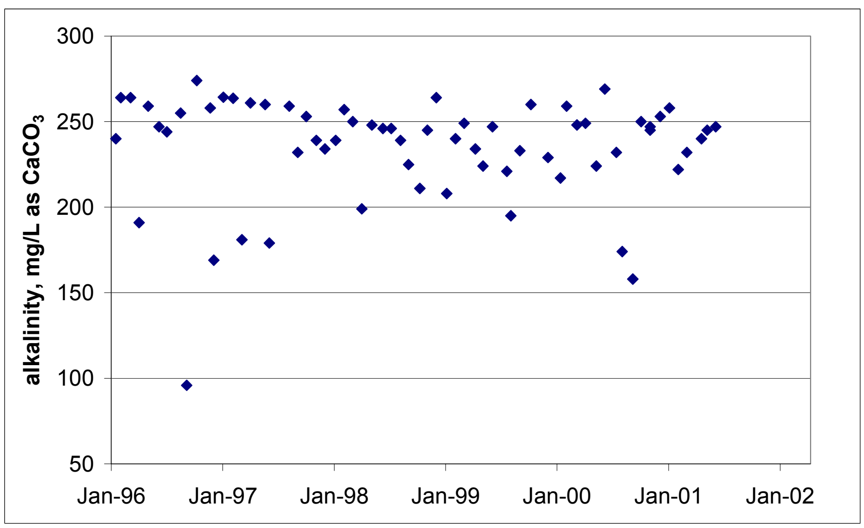

Figure 4.3. Alkalinity Concentration in Abrams Creek

Nutrients

DEQ's Threatened Waters threshold of 0.2 mg/L total phosphorus has been exceeded 3 times during the period of record. However, except for 4 samples, all other TP measurements were either at, or below, the minimum detection limit (MDL). Additionally, no TP exceedences have been reported during the last 4 years (Figure 4.4). The five-year average concentrations of dissolved nitrogen (1.71 mg/L NO_3-N) and phosphorus (0.021 mg/L PO_4-P) in Abrams Creek are both above levels needed for eutrophic growth. However, these concentrations are comparable to average NO_3-N concentrations (1.65 mg/L), and much less than average PO_4-P concentrations (0.222

mg/L), in the neighboring Upper Opequon Creek which has a healthy benthic community. In addition, a special diurnal DO study conducted on August 12-13, 2002 (Figure 4.9) also did not show any night time violations of the DO standard. These data tend to indicate that nutrients are not contributing to a eutrophication problem that would depress DO levels sufficiently to stress the benthic community. Nutrients do not appear to be stressing the benthic community in Abrams Creek.

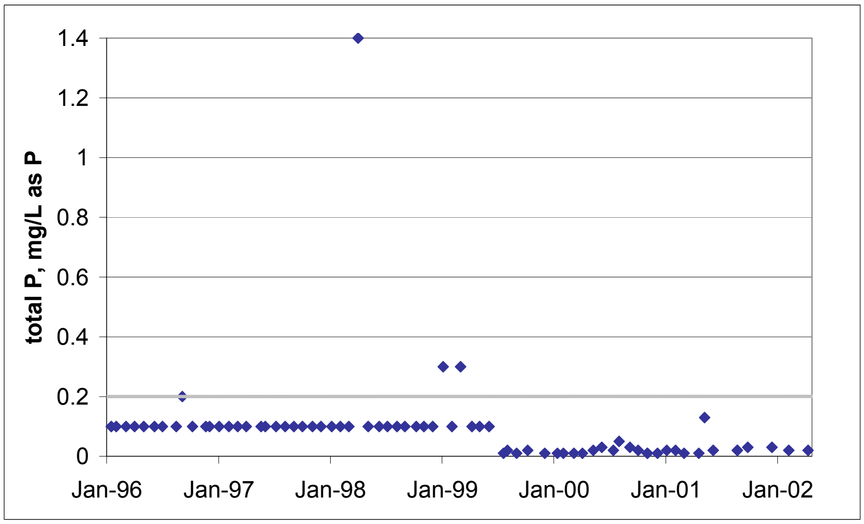

Figure 4.4. Total Phosphorus Concentrations in Abrams Creek

Toxics

Abrams Creek watershed does include considerable industry. There are 5 permitted VPDES dischargers, but no incidences of toxic waste spills have been reported by DEQ. Table 4.1 shows the results from periodic DEQ analyses of water column toxics from Abrams Creek since 1985. Of the 12 metals analyzed, 5 were not detected, and none of the others exceeded any of the Aquatic Life or Human Health criteria, where available.

Three sets of stream sediment toxics samples were analyzed since 1985 in Abrams Creek, as shown in Table 4.2. Measured concentrations of toxics in sediments from Abrams Creek were compared to consensus-based probable effect concentrations (PEC; MacDonald et al., 2000) to determine if observed levels of these toxics were sufficient to cause the benthic impairment. This approach is consistent with recent DEQ guidance on assessing the quality of the State's waters.

Of the 13 metals analyzed, 3 were not detected in 1996, and 5 were not detected in 1999. None of the metals exceeded their corresponding PECs – the level above which adverse effects are expected to occur more often than not - in the first two samples. None of the 11 organic compounds analyzed for were detected in the first two samples. Therefore, toxicity does not appear to be a cause of historical benthic stress in Abrams Creek. However, in the most recent sample, chlordane – a banned pesticide – was detected at a concentration exceeding the consensus-based PEC and may add to the other source(s) of current stress on the benthic community.

Table 4.1. DEQ Water Column Toxics Data Since 1985 – Abrams Creek

				Freshwater			
				Aquatic Life Criteria		Human Health	
		1AABR000.78		Chronic	Acute	PWS	Other
ParamCode	Parameter	6/29/1999 10:15		(ug/L)	(ug/L)	(ug/L)	(ug/L)
1106	ALUMINUM, DISSOLVED (UG/L AS AL)	1	U				
1095	ANTIMONY, DISSOLVED (UG/L AS SB)	0.2					
1000	ARSENIC, DISSOLVED (UG/L AS AS)	0.4		190	360		
1025	CADMIUM, DISSOLVED (UG/L AS CD)	0.1	U	1.1	3.9		
1030	CHROMIUM, DISSOLVED (UG/L AS CR)	0.3		210	1700		
1040	COPPER, DISSOLVED (UG/L AS CU)	0.8		12	18		
1046	IRON, DISSOLVED (UG/L AS FE)	50	U				
1049	LEAD, DISSOLVED (UG/L AS PB)	0.1	U	14	120	15	
925	MAGNESIUM, DISSOLVED (MG/L AS MG)	18.8					
1056	MANGANESE, DISSOLVED (UG/L AS MN)	4.1					
71890	MERCURY, DISSOLVED (UG/L AS HG)	0.2	U	0.012	2.4	0.052	0.053
1065	NICKEL, DISSOLVED (UG/L AS NI)	0.5		20	180	610	4600

U = analyzed, but not detected. Value is limit of detection.

Table 4.2. DEQ Sediment Toxics Data Since 1985 – Abrams Creek

ParamCode	Parameter	1AABR000.78 7/24/1996 13:15		1AABR000.78 7/20/1999 13:15		1AABR000.78 8/20/2001		Consensus-Based PEC
1108	ALUMINUM, SEDIMENT (MG/KG AS AL DRY WGT)	12200		13900		0.65		
1098	ANTIMONY, SEDIMENT (MG/KG AS SB DRY WGT)	7		5	U	0.5	U	
1003	ARSENIC, SEDIMENT (MG/KG DRY WT)	6		5	U	0.5	U	33
1013	BERYLLIUM, SED (MG/KG AS BE DRY WT)	5	U	5	U			
1028	CADMIUM, SEDIMENT (MG/KG DRY WT)	5	U	5	U	0.57		4.98
1029	CHROMIUM, SEDIMENT (MG/KG DRY WT)	29		27.5		11		111
1043	COPPER, SEDIMENT (MG/KG AS CU DRY WT)	60		26.2		43		149
1170	IRON, SEDIMENT (MG/KG AS DRY WT)	25600		20000				
1052	LEAD, SEDIMENT (MG/KG AS PB DRY WT)	23		50.4		45		128
1053	MANGENESE, SEDIMENT (MG/KG AS DRY WT)	328		534				
71921	MERCURY, SEDIMENT (MG/KG AS HG DRY WT)	0.3	U	0.3	U	0.74		1.06
1068	NICKEL, SEDIMENT (MG/KG DRY WT)	20		21		13		48.6
1093	ZINC, SEDIMENT (MG/KG AS ZN DRY WT)	84		123		143		459
39333	ALDRIN, SEDIMENT (UG/KG DRY WT)	30	U	30	U			
39351	CHLORDANE TECH MIX & METABS,SEDIMENT(UG/	40	U	90	U	18.79		17.6
39363	DDD, SEDIMENT (UG/KG DRY WT)	20	U	50	U	12.21		28
39368	DDE, SEDIMENT (UG/KG DRY WT)	20	U	50	U	4.48		31.3
39373	DDT, SEDIMENT (UG/KG DRY WT)	30	U	50	U	29.94		62.9
	DDT, TOTAL (UG/KG DRY WT)					46.63		572
79799	DICOFOL (KELTHANE)	80	U	110	U			
39383	DIELDRIN, SEDIMENT (UG/KG DRY WT)	20	U	30	U			61.8
39393	ENDRIN, SEDIMENT (UG/KG DRY WT)	30	U	70	U			207
75045	HEPTACHLOR EPOXIDE, SED (UG/KG DRY WT)	20	U	30	U			16
39413	HEPTACHLOR, SEDIMENT (UG/L)	20	U	30	U			
39526	PCBS TOTAL,SEDIMENT (UG/KG DRY WT)	30	U	30	U	40.15		676

U = analyzed, but not detected. Value is limit of detection.
TEC = threshold effect concentration; PEC = probable effect concentration.

Benthic macro-invertebrate samples indicate a moderately low, but stable, total number of benthic organisms, as well as the number of pollution sensitive species. One component of the benthic population known as shredders has been highly variable, and disappeared during the last sample, but this is more likely due to smothering of shredder habitat by sediment, rather than a toxic effect. There have been no ammonia standard (variable standard dependent on pH and temperature - the chronic limit ranges from 0.19 mg/L at pH 9 and 5°C to 3.02 mg/L at pH 6.5 and 0°C) violations monitored by DEQ (Figure 4.5), and chloride concentrations are well below Virginia's Public Water Supply water quality criterion of 250 mg/L (Figure 4.6). These data further support the position of toxics as non-stressors in Abrams Creek.

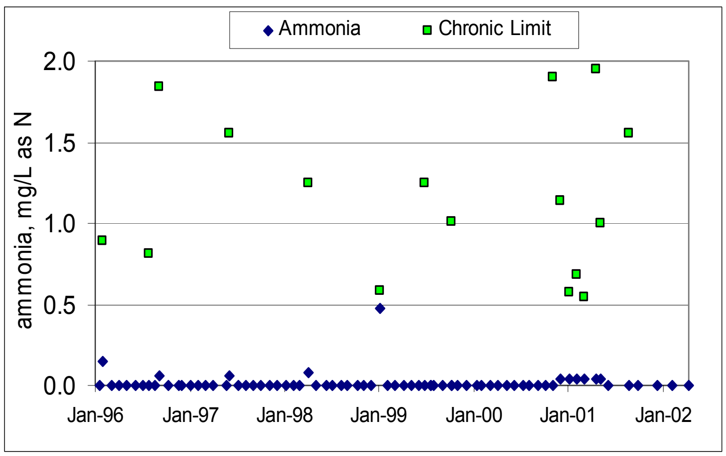

Figure 4.5. Ammonia Concentrations in Abrams Creek

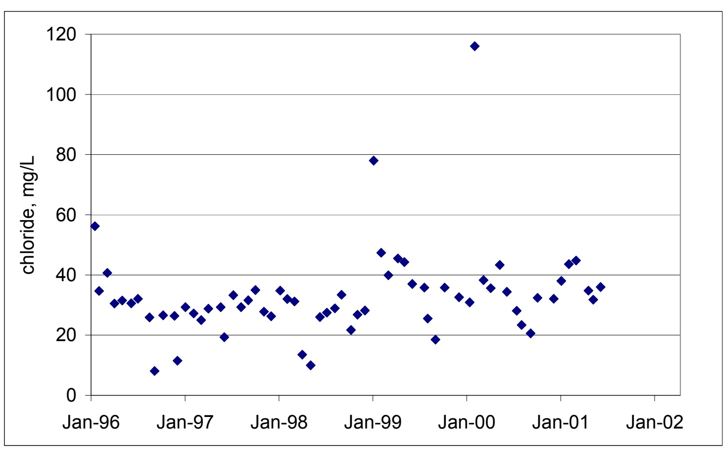

Figure 4.6. Chloride Concentrations in Abrams Creek

4.2.2. Possible Stressors

Organic Matter

Organic matter can affect water quality in either the dissolved or particulate form. Dissolved organics would be reflected in measurements of 5-day biological oxygen demand (BOD_5), while particulate organics may be reflected in measurements of total organic carbon (TOC), chemical oxygen demand (COD), and volatile solids (VS). Decomposition of organic substances would result in decreased levels of measured dissolved oxygen (DO). On the dissolved side, all recent BOD measurements (Figure 4.7) have been near, or below, their minimum detection limit (MDL). Monthly ambient DO concentrations (Figure 4.8) are all at desirable high levels, well above the minimum water quality standard of 5 mg/L. A special diurnal DO study conducted on August 12-13, 2002 (Figure 4.9) also did not show any night-time violations of the DO standard. These data tend to indicate that dissolved organic matter is not stressing the benthic community.

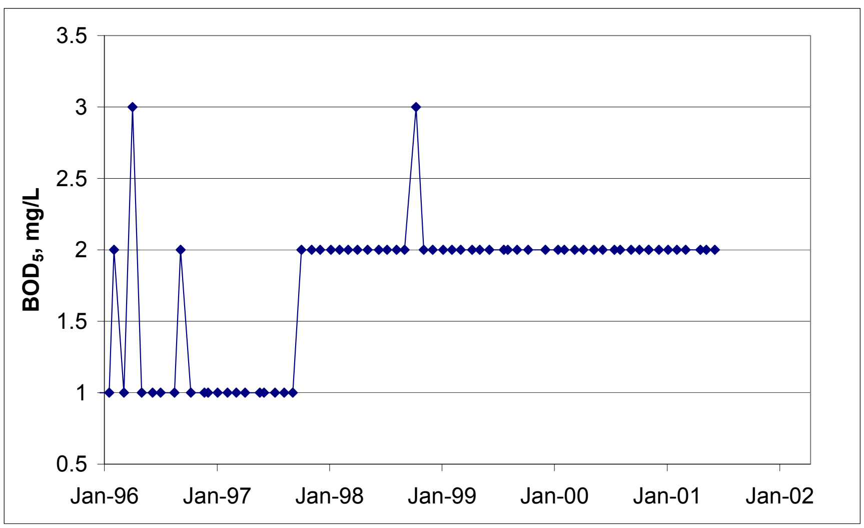

Figure 4.7. Biological Oxygen Demand (5-day) Concentration in Abrams Creek

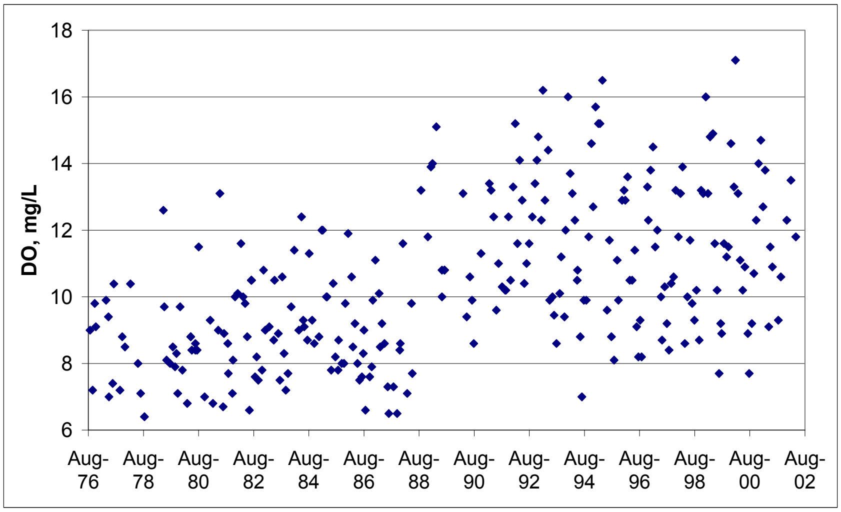

Figure 4.8. Monthly Dissolved Oxygen Concentration in Abrams Creek

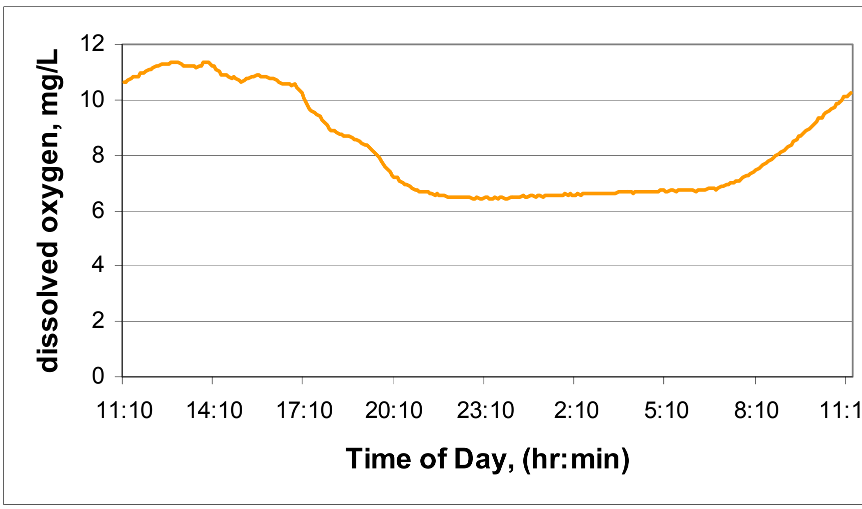

Figure 4.9. Diurnal DO Concentration in Abrams Creek, August 12-13, 2002

On the particulate side, TOC (Figure 4.10) measurements are generally less than Virginia groundwater criteria of 10 mg/L, and COD (Figure 4.11) measurements are generally less than 20 mg/L, a level well below most STP permitted weekly average effluent limits, though both measurements were discontinued during the late 1990's. However, one of the benthic metrics that indicates moderate levels of organic matter - the MFBI - is moderately high (Table 3.2). Two netspinners who thrive on particulate organic matter - *Hydropsychidae* and *Chironimidae* - are the dominant benthic species (Table 3.1). In addition, murky grey water was observed originating from an industrial site during one runoff event. This evidence indicates the possibility that particulate organic matter may be stressing the benthic community.

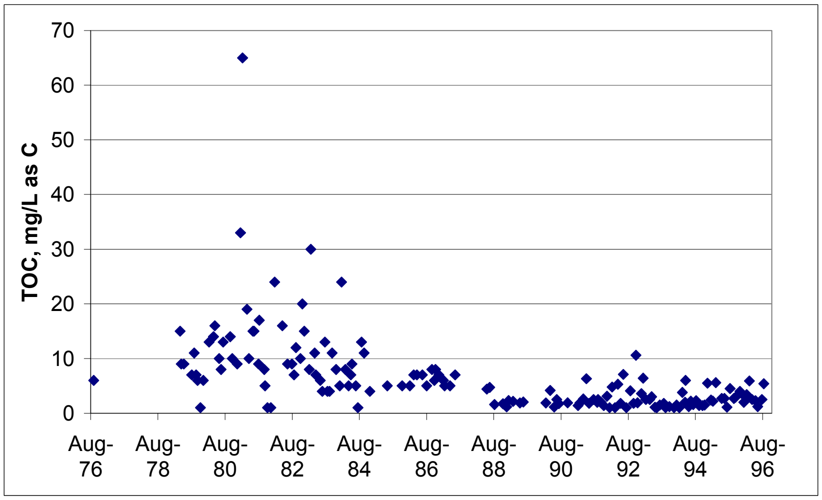

Figure 4.10. Total Organic Carbon Concentration in Abrams Creek

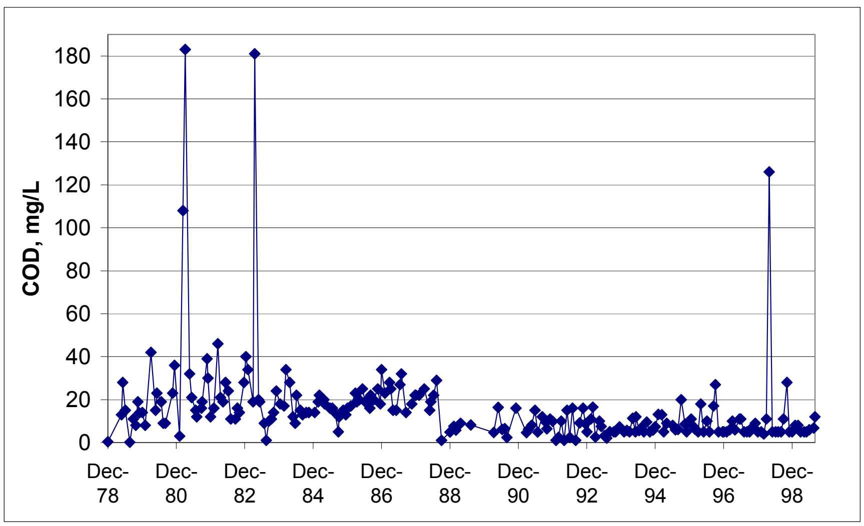

Figure 4.11. Chemical Oxygen Demand Concentration in Abrams Creek

4.2.3. Most Probable Stressor

Excessive sedimentation is considered to be a primary cause of the benthic impairment in Abrams Creek. This determination was based on ambient water quality monitoring, benthic and habitat assessment metrics, modeling of sediment loads compared to reference conditions, in-stream observation, and best professional judgement.

Total suspended solids (TSS) data (Figure 4.12) indicate predominantly low levels within normal ranges, with one very large spike in 1998. Turbidity data (not shown) parallels TSS data. The 1998 spike was not considered sufficient to cause the impairment, so TSS does not appear to be a stressor. Although corroborating flow data was not available for the time period shown in Figure 4.12, high suspended solids are common during high flow events and may result from channel erosion, erosion from adjacent land surfaces, and transport of the sediment bed load.

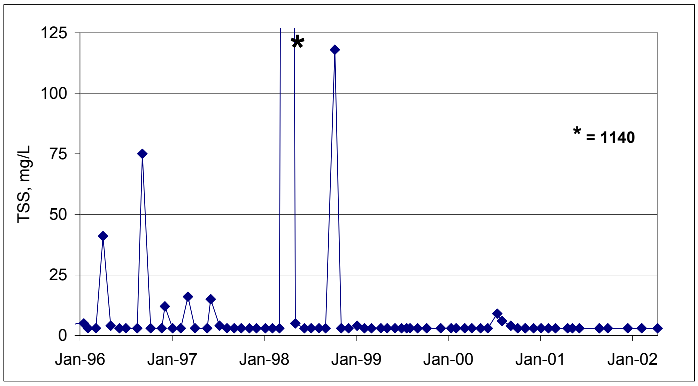

Figure 4.12. Suspended Solids Concentration in Abrams Creek

In addition to increased sediment transport during large runoff events, the benthic assessment scores for "% Haptobenthos" (Table 3.3) were low, indicating poor habitat for functional groups requiring a clean course substrate. Abrams Creek also received repeated low habitat scores for embeddedness, which indicates a blanketing of course substrate by sediment. Observations within the watershed and along the stream channel also supported the choice of sedimentation as a primary cause of the benthic impairment. Damage to stream banks from livestock trampling, construction within the watershed, and reduced riparian and streambank vegetation were observed. The majority of Town Run, a tributary to Abrams Creek, was observed as being armored, increasing the likelihood for scouring and stream bank erosion further downstream. Collectively, these observations and monitoring assessment results indicate that sedimentation is a primary cause of the benthic impairment in Abrams Creek. To eliminate the impairment due to sedimentation, a TMDL for sediment will be developed for this stream.

In addition to sedimentation, habitat alteration is likely another primary cause of the benthic impairment in Abrams Creek. Habitat alteration involves a change in the physical stream environment, including flow regimes, substrate, channel morphology, riparian vegetation, and other physical factors that limit the amount of habitable space for benthic macroinvertebrates. In Abrams Creek several physical conditions that potentially degrade available habitat were observed. Urban development in the Abrams Creek watershed, particularly the construction of buildings, parking lots and other impervious surfaces within the floodplain and riparian areas, has resulted in alterations to the physical structure of the stream channel and its flow regime. Within this urban setting, the stream has been channelized, the stream bottom has been armored, and riparian vegetation is lacking. Within agricultural areas of the watershed, intensive use of riparian areas for agricultural production has also reduced riparian vegetation and destabilized stream banks.

These physical habitat alterations are closely interrelated with sedimentation. While many physical conditions directly impact available habitat, many also act through increasing erosion and sedimentation, smothering available bottom habitat. Channelization of the stream and armoring of the stream bottom, for example, directly impact habitat by removing available substrate and eliminating substrate diversity. Channelization and armoring also increases erosion and sedimentation downstream by increasing flow velocities and scouring stream bottoms and stream banks.

Because habitat alteration is not a “pollutant”, a TMDL cannot be developed for this stressor. The interrelation between habitat alteration and sedimentation, however, allows the TMDL developed for sediment to address habitat alteration as well. Best management practices expected to be used in reducing sediment loads will also benefit habitat conditions. For instance, establishment of riparian vegetation reduces sediment loads from stream bank erosion and also improves habitat conditions by other means such as increasing energy inputs from leaf fall. This increases food resources for shredders and other benthic macroinvertebrates that rely on course particulate organic matter, and reduces direct sunlight that moderates stream temperatures and decreases algal growth. By implementing the sediment TMDL, it is believed that associated habitat improvements will also be achieved.

4.3. Lower Opequon Creek Stressor Analysis

4.3.1. Non-Stressors

<u>Temperature</u>

Although the habitat evaluation indicated that riparian vegetation on the Lower Opequon Creek is not ideal (Table 3.6), the reduction in vegetation appeared not to affect stream water temperature, which has fluctuated within normal bounds during the

21 years of monitored data and has never exceeded Virginia's maximum water quality standard of 31°C for Class IV waters, as shown in Figure 4.13. Temperature does not appear to be a stressor.

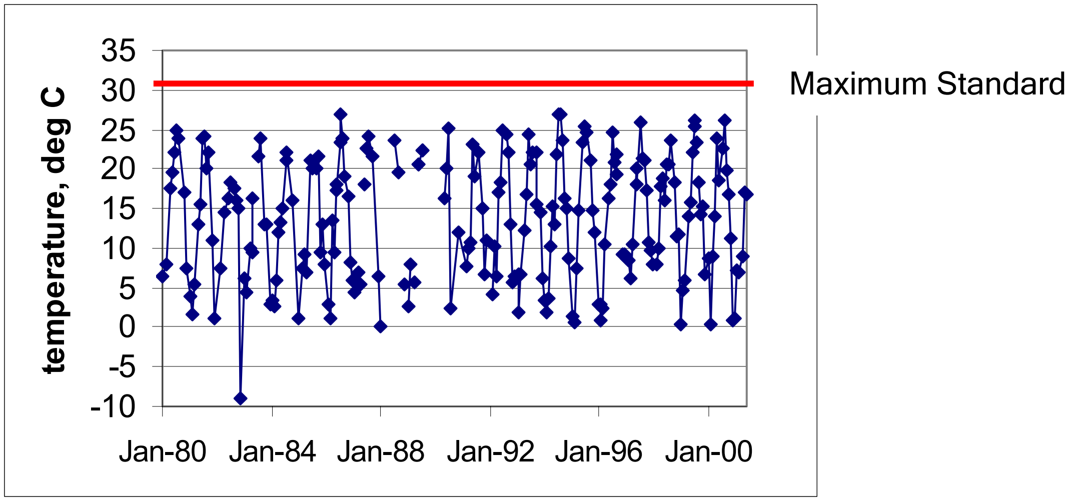

Figure 4.13. Water Temperature in Lower Opequon Creek

pH

All pH values fall between the minimum standard of 6 and the maximum standard of 9 (Figure 4.14), with one exception. Alkalinity concentrations, which may reflect influences and/or effects of pH, also appear fairly constant and within the normal range of 30-500 mg/L for the Northern Appalachian Ridges and Valley physiographic region (Figure 4.15). Therefore, pH was eliminated as a possible stressor on the Lower Opequon Creek benthic community.

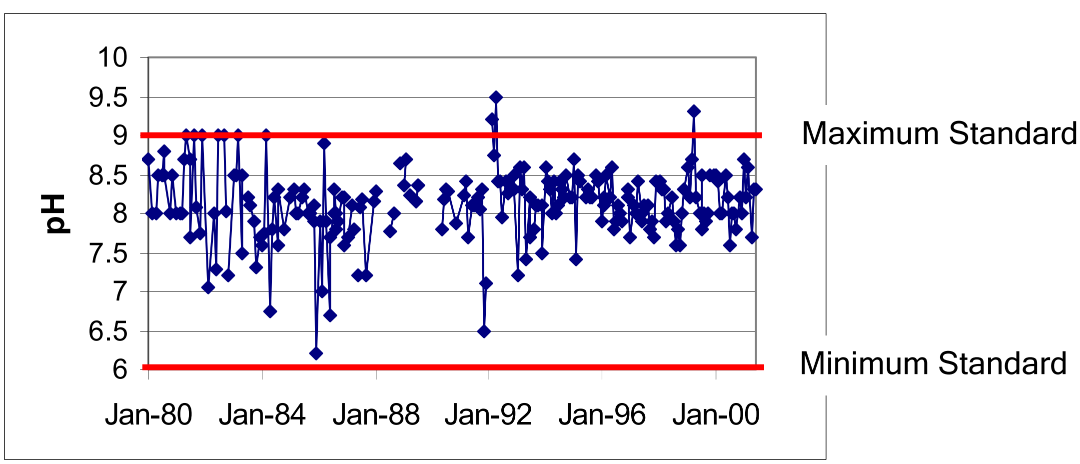

Figure 4.14. Field pH Data for Lower Opequon Creek

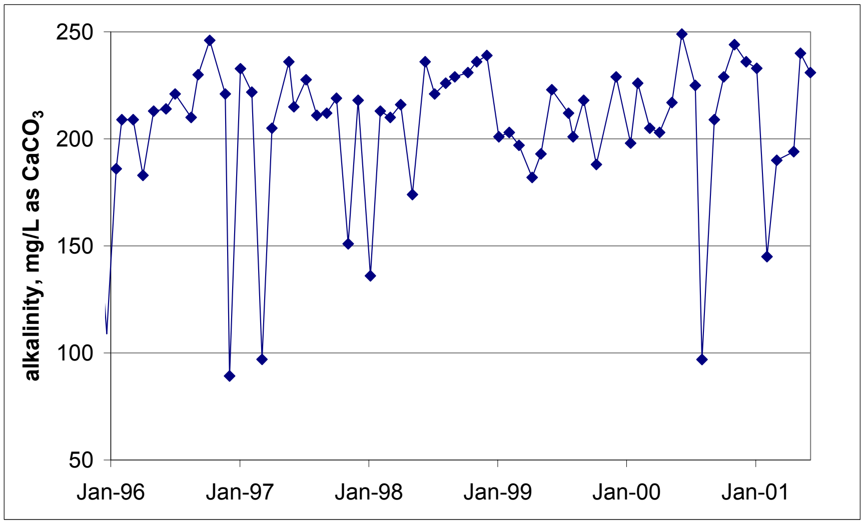

Figure 4.15. Alkalinity Concentration in Lower Opequon Creek

Toxics

The Opequon Creek watershed does include numerous industries. There are 12 permitted VPDES dischargers, but no incidences of toxic waste spills have been reported by DEQ. Table 4.3 shows the results from DEQ analyses of water column toxics from Lower Opequon Creek since 1985. Of the 12 metals analyzed, 4 were not detected, and none of the others exceeded any of the Aquatic Life or Human Health criteria, where available.

Three sets of stream sediment toxics samples taken on four different dates were analyzed since 1985 in Lower Opequon Creek, as shown in Table 4.4. Measured concentrations of toxics in sediments from Lower Opequon Creek were compared to consensus-based probable effect concentrations (PEC; MacDonald et al., 2000) to determine if observed levels of these toxics were sufficient to cause the benthic impairment. This approach is consistent with recent DEQ guidance on assessing the quality of the State's waters.

Of the 13 metals analyzed, 3 were not detected in 1996, and 4 were not detected in 1999. None of the metals exceeded their corresponding consensus-based PECs - the level above which adverse effects are expected to occur more often than not - in the first two sample sets. None of the 11 organic compounds analyzed for were detected either in the first two sample sets. Therefore, toxicity does not appear to be a cause of historical benthic stress in Lower Opequon Creek. However, in the most recent sample, mercury was detected at a concentration exceeding the consensus-based PEC and may add to the other source(s) of current stress on the benthic community.

Table 4.3. DEQ Water Column Toxics Data Since 1985 – Lower Opequon Creek

				Freshwater			
				Aquatic Life Criteria		Human Health	
ParamCode	Parameter	1AOPE025.10 6/29/1999 9:20		Chronic (ug/L)	Acute (ug/L)	PWS (ug/L)	Other (ug/L)
1106	ALUMINUM, DISSOLVED (UG/L AS AL)	1	U				
1095	ANTIMONY, DISSOLVED (UG/L AS SB)	0.1					
1000	ARSENIC, DISSOLVED (UG/L AS AS)	0.8		190	360		
1025	CADMIUM, DISSOLVED (UG/L AS CD)	0.1	U	1.1	3.9		
1030	CHROMIUM, DISSOLVED (UG/L AS CR)	0.2		210	1700		
1040	COPPER, DISSOLVED (UG/L AS CU)	2		12	18		
1046	IRON, DISSOLVED (UG/L AS FE)	50	U				
1049	LEAD, DISSOLVED (UG/L AS PB)	0.1		14	120	15	
925	MAGNESIUM, DISSOLVED (MG/L AS MG)	20					
1056	MANGANESE, DISSOLVED (UG/L AS MN)	7.6					
71890	MERCURY, DISSOLVED (UG/L AS HG)	0.2	U	0.012	2.4	0.052	0.053
1065	NICKEL, DISSOLVED (UG/L AS NI)	0.9		20	180	610	4600

U = analyzed, but not detected. Value is limit of detection.

Table 4.4. DEQ Sediment Toxics Data Since 1985 – Lower Opequon Creek

ParamCode	Parameter	1AOPE025.10 7/24/1996 13:45		1AOPE025.10 7/20/1999 14:00		1AOPE025.10 8/2/1999 9:45		1AOPE025.10 8/22/2001		Consensus-Based PEC
1108	ALUMINUM, SEDIMENT (MG/KG AS AL DRY WGT)	16900				11900		0.24		
1098	ANTIMONY, SEDIMENT (MG/KG AS SB DRY WGT)	14				5	U	0.5	U	
1003	ARSENIC, SEDIMENT (MG/KG DRY WT)	8				5.7		3.5		33
1013	BERYLLIUM, SED (MG/KG AS BE DRY WT)	5	U			5	U			
1028	CADMIUM, SEDIMENT (MG/KG DRY WT)	5	U			5	U	0.25		4.98
1029	CHROMIUM, SEDIMENT (MG/KG DRY WT)	27				34.2		50		111
1043	COPPER, SEDIMENT (MG/KG AS CU DRY WT)	50				27		51		149
1170	IRON, SEDIMENT (MG/KG AS DRY WT)	26800				29000				
1052	LEAD, SEDIMENT (MG/KG AS PB DRY WT)	37				27.5		28		128
1053	MANGENESE, SEDIMENT (MG/KG AS DRY WT)	657				725				
71921	MERCURY, SEDIMENT (MG/KG AS HG DRY WT)	0.3	U			0.3	U	1.8		1.06
1068	NICKEL, SEDIMENT (MG/KG DRY WT)	23				23		18		48.6
1093	ZINC, SEDIMENT (MG/KG AS ZN DRY WT)	109				86.5		124		459
39333	ALDRIN, SEDIMENT (UG/KG DRY WT)	30	U	20	U					
39351	CHLORDANE TECH MIX & METABS,SEDIMENT(UG/K	40	U	80	U					17.6
39363	DDD, SEDIMENT (UG/KG DRY WT)	20	U	40	U			4.74		28
39368	DDE, SEDIMENT (UG/KG DRY WT)	20	U	40	U					31.3
39373	DDT, SEDIMENT (UG/KG DRY WT)	30	U	40	U			38.18		62.9
	DDT, TOTAL (UG/KG DRY WT)							42.92		572
79799	DICOFOL (KELTHANE)	80	U	90	U					
39383	DIELDRIN, SEDIMENT (UG/KG DRY WT)	20	U	20	U					61.8
39393	ENDRIN, SEDIMENT (UG/KG DRY WT)	30	U	60	U					207
75045	HEPTACHLOR EPOXIDE, SED (UG/KG DRY WT)	20	U	20	U					16
39413	HEPTACHLOR, SEDIMENT (UG/L)	20	U	20	U			0.96		
39526	PCBS TOTAL,SEDIMENT (UG/KG DRY WT)	30	U	20	U			67.37		676

U = analyzed, but not detected. Value is limit of detection.
TEC = threshold effect concentration; PEC = probable effect concentration.

Benthic macro-invertebrate samples indicate a moderate total number of benthic organisms that have decreased slightly over the years, and a moderately low, but stable, number of pollution sensitive species. One component of the benthic population known as shredders has been totally missing during 4 of the last 5 samples, but this is more likely due to sediment smothering shredder habitat, rather than a toxic effect. There have been no ammonia standard exceedences monitored by DEQ (Figure 4.16), and chloride concentrations are well below Virginia's Public Water Supply water quality criterion of 250 mg/L (Figure 4.17). These data further support the position of toxics as non-stressors in Lower Opequon Creek.

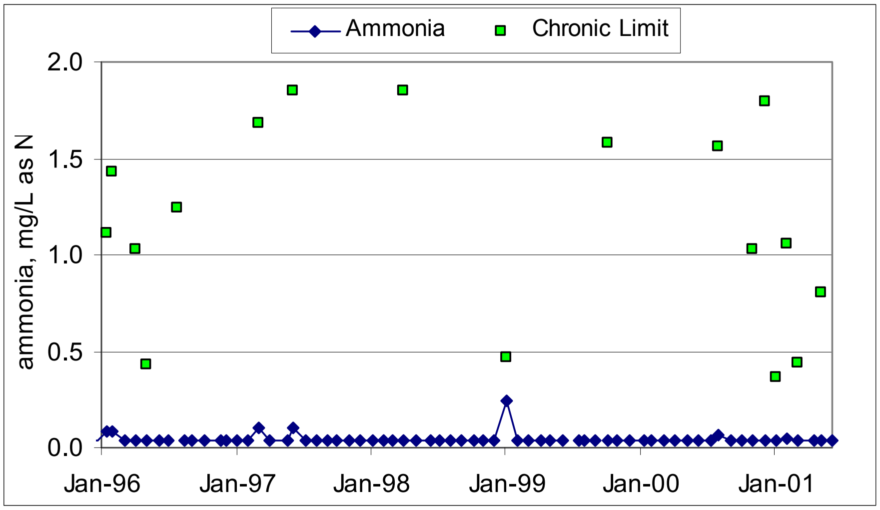

Figure 4.16. Ammonia Concentrations in Lower Opequon Creek

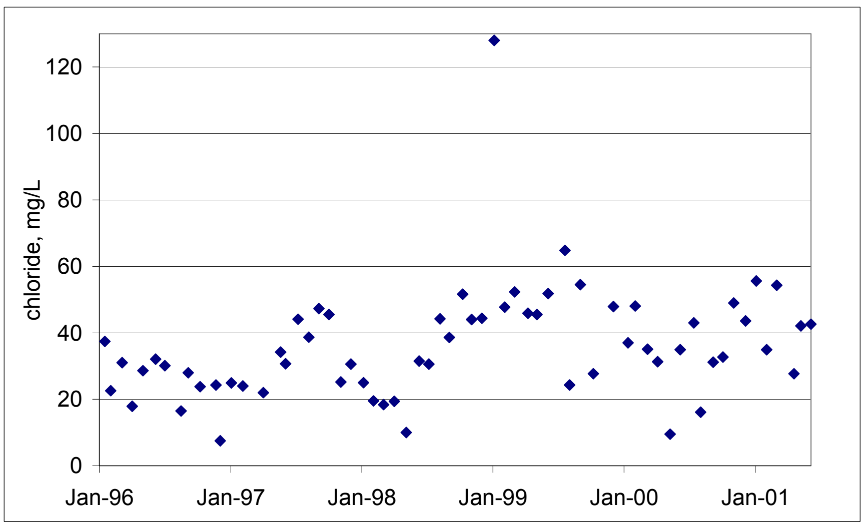

Figure 4.17. Chloride Concentrations in Lower Opequon Creek

4.3.2. Possible Stressors

Organic Matter

Organic matter can affect water quality in either the dissolved or particulate form. Dissolved organics would be reflected in measurements of 5-day biological oxygen demand (BOD_5), while particulate organics may be reflected in measurements of total organic carbon (TOC), chemical oxygen demand (COD), and volatile solids (VS). Decomposition of organic substances would result in decreased levels of measured dissolved oxygen (DO). On the dissolved side, all recent BOD measurements (Figure 4.18) have been near, or below, their minimum detection limit (MDL). Monthly ambient

DO concentrations (Figure 4.19) are all at desirable high levels, well above the minimum water quality standard of 5 mg/L. A special diurnal DO study conducted on August 12-13, 2002 (Figure 4.20) also did not show any night time violations of the DO standard. These data tend to indicate that dissolved organic matter is not stressing the benthic community.

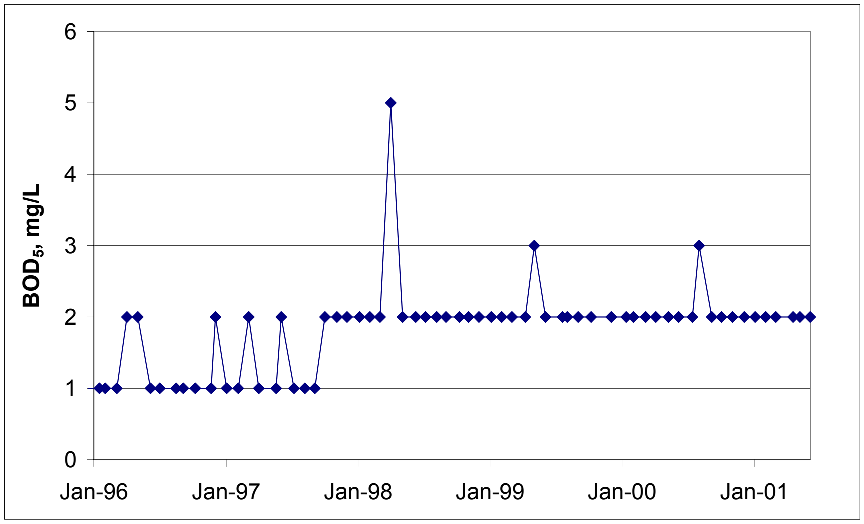

Figure 4.18. Biological Oxygen Demand (5-day) Concentration in Lower Opequon Creek

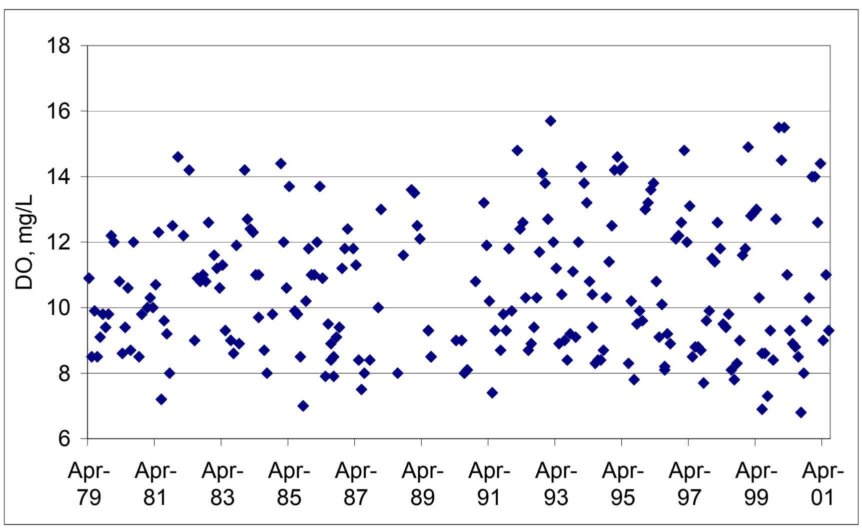

Figure 4.19. Monthly Dissolved Oxygen Concentration in Lower Opequon Creek

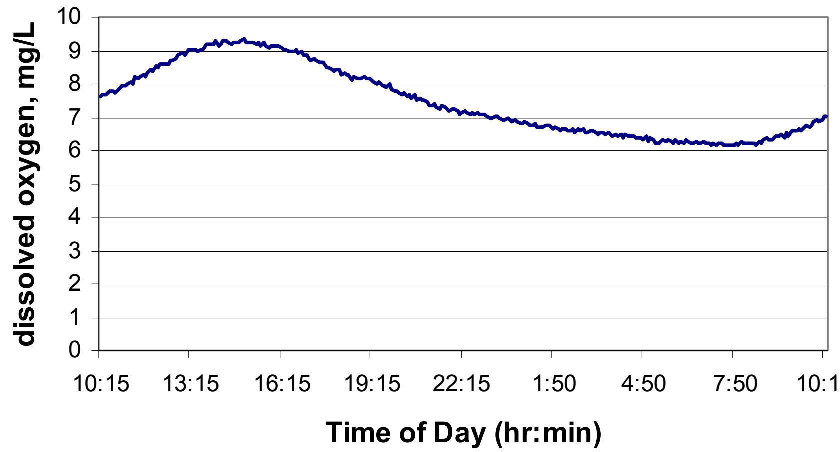

Figure 4.20. Diurnal DO Concentration in Lower Opequon Creek, August 12-13, 2003

On the particulate side, TOC (Figure 4.21) measurements are generally below the Virginia groundwater criteria of 10 mg/L, and COD (Figure 4.22) measurements are generally below 20 mg/L, a level well below most STP permitted weekly average effluent levels, though both measurements were discontinued during the 1990's. One of the benthic metrics that indicates moderate levels of organic matter - the MFBI - is moderately high. The species *Hydropsychidae* - netspinners who thrive on particulate organic matter - was only dominant in 1 of the 10 samples (Fall 1998), while *Chironomidae* and *Elmidae* are each dominant in 4 samples (Table 3.5). Since *Elmidae* are one of the species of mayflies in our area that indicate better water quality, it is not likely that particulate organic matter is stressing the benthic community.

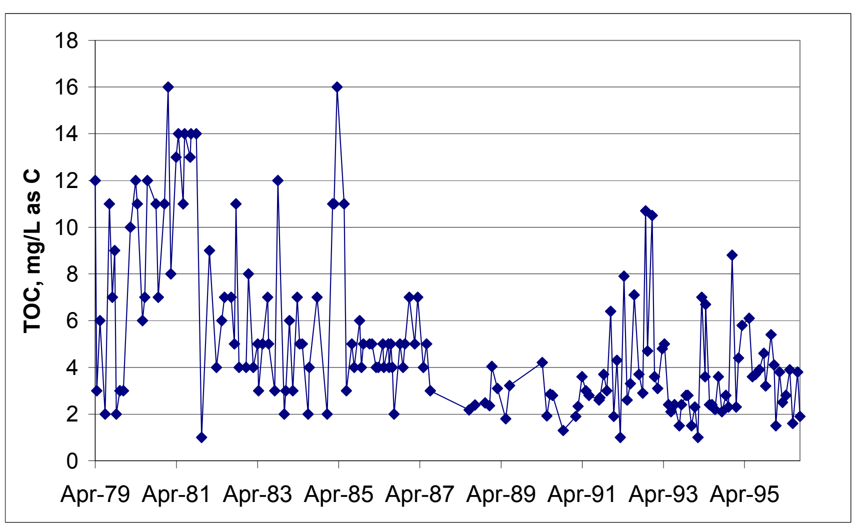

Figure 4.21. Total Organic Carbon Concentration in Lower Opequon Creek

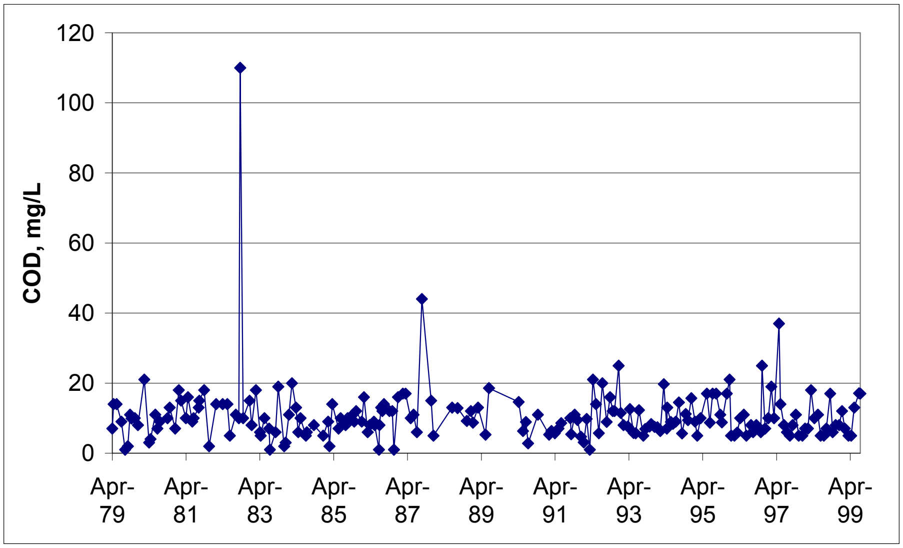

Figure 4.22. Chemical Oxygen Demand in Lower Opequon Creek

<u>Nutrients</u>

DEQ's Threatened Waters threshold of 0.2 mg/L total phosphorus has been exceeded 31 times since January 1996 (Figure 4.23), and although nitrate levels are below the drinking water standard, they are much higher than most monitoring stations in the area (Figure 4.24). Five-year average concentrations of dissolved nitrogen (2.58 mg/L NO_3-N) and phosphorus (0.247 mg/L PO_4-P) in the Lower Opequon Creek are both above levels needed for eutrophic growth. Additionally, these concentrations are much greater than average NO_3-N concentrations (1.65 mg/L), and slightly above average PO_4-P concentrations (0.222 mg/L), in the neighboring Upper Opequon Creek which has a healthy benthic community. The majority of both nutrients are in the dissolved form. High concentrations of dissolved N and P have also been reported by DEQ in its periodic inspection reports for several of the permitted VPDES dischargers in the watershed draining to the Lower Opequon (Table 4.5). The impact of primary concern between elevated nutrients and the benthic community is that of reduced DO. Although dissolved nutrient levels are exceedingly high, ambient DO concentrations are at acceptable levels and a special diurnal DO study conducted on August 12-13, 2002 (Figure 4.20) also did not show any night time violations of the DO standard, indicating that eutrophic conditions probably do not exist. Nutrients thus are not a current stressor to the benthic community, but are at levels that present a potential for becoming a future stressor on the benthic community.

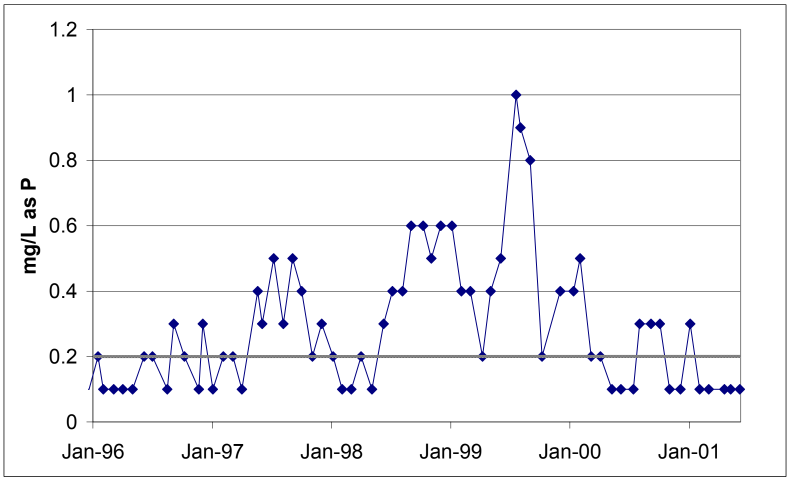

Figure 4.23. Total Phosphorus Concentration in Lower Opequon Creek

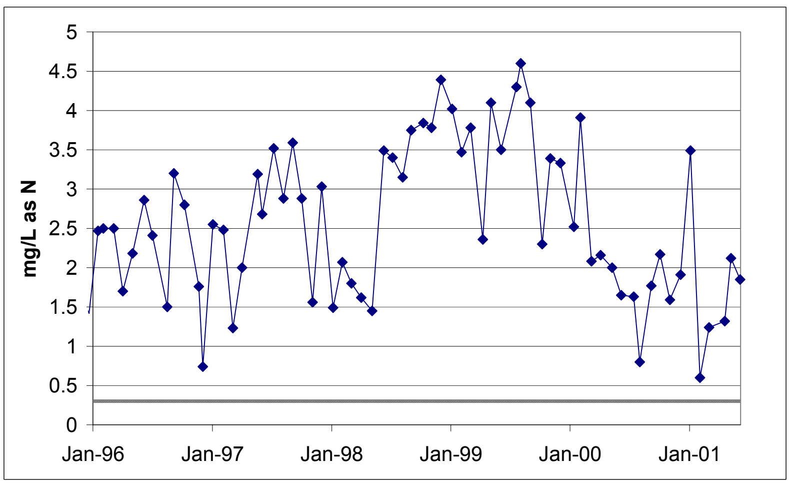

Figure 4.24. Nitrate Concentrations in Lower Opequon Creek

Table 4.5. DEQ Periodic Inspection Report Excerpts in Lower Opequon Creek

Date	Ortho-P (mg/L)	Total P (mg/L)	Nitrate-N (mg/L)	Total N (mg/L)	Chloride (mg/L)	TSS (mg/L)	COD (mg/L)
VA0023116 I-81 Rest Area							
02/26/01	5.94	7.90	76.79	79.29	116	8	50.2
VA0065552 Opequon Regional AWT							
02/17/99	2.70	3.00	15.06	16.86	159	3	21.0
12/02/99	3.00	3.00	15.22	17.42	144	3	8.0
09/13/00	0.20	0.20	3.70	4.90	154	3	16.0
09/12/01	0.04	0.20	4.63	5.83	165	3	16.7
VA0075191 Parkins Mill STP							
04/22/99	1.03	1.40	2.78	4.78	82	3	17.0
06/28/00	2.63	?	2.38	5.08	56	3	17.0
04/02/02	4.12	5.40	9.22	10.92	196	3	23.2
VA0088722 Stonebrook Swim/Racquet Club							
06/03/98	4.27	3.90	24.20	26.90	920	4	21.0

4.3.3. Most Probable Stressor

Excessive sedimentation is considered to be a primary cause of the benthic impairment in Lower Opequon Creek. This determination was based on ambient water quality monitoring, benthic and habitat assessment metrics, modeling of sediment loads compared to reference conditions, in-stream observation, and best professional judgement.

Total suspended solids (TSS) data (Figure 4.25) indicate predominantly low levels within normal ranges, with infrequent spikes. Turbidity data (not shown) parallels the TSS data. The periodic spikes were not deemed sufficient to cause the impairment, so TSS is not considered to be a stressor in the Lower Opequon Creek. Although corroborating flow data was not available for the Lower Opequon, high suspended solids are common during high flow events and may result from channel erosion, erosion from adjacent land surfaces, and transport of the sediment bed load.

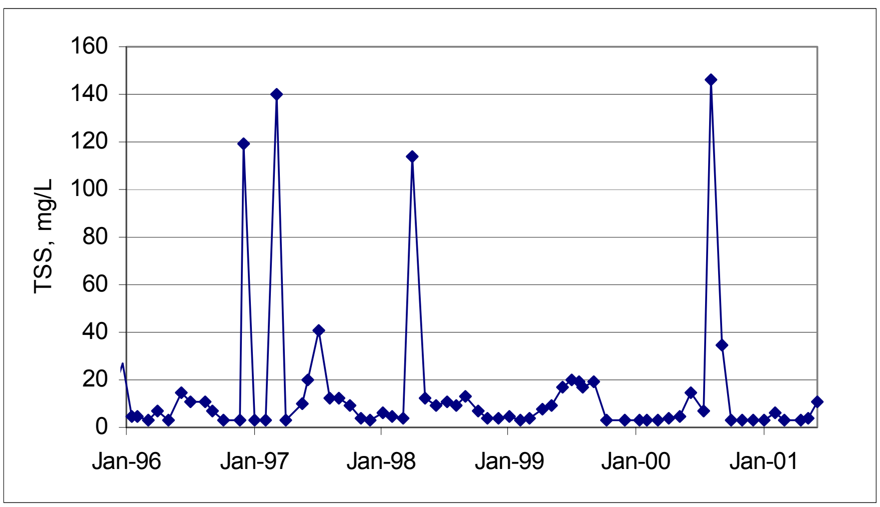

Figure 4.25. Suspended Solids Concentration in Lower Opequon Creek

In addition to increased sediment transport during large runoff events, the benthic assessment scores for “% Haptobenthos” (Table 3.5) were low, indicating poor habitat for functional groups requiring a clean course substrate. Lower Opequon Creek also received repeated low habitat scores for substrate availability and embeddedness, which indicate a blanketing of course substrate by sediment. Observations within the watershed and along the stream channel also supported the choice of sedimentation as a primary cause of the benthic impairment. The Town Run tributary to Abrams Creek which flows into Lower Opequon Creek is predominantly armored, increasing the likelihood for scouring and stream bank erosion along the Lower Opequon. Collectively, these observations and monitoring assessment results indicate that sedimentation is a primary cause of the benthic impairment in Lower Opequon Creek. To eliminate the impairment due to sedimentation, a TMDL for sediment will be developed for this stream.

In addition to sedimentation, habitat alteration is likely another primary cause of the benthic impairment in Lower Opequon Creek. Habitat alteration involves a change in the physical stream environment, including flow regimes, substrate, channel morphology, riparian vegetation, and other physical factors that limit the amount of habitable space for benthic macroinvertebrates. In Lower Opequon Creek several physical conditions that potentially degrade available habitat were observed. Suburban development in the Lower Opequon Creek watershed, particularly the increase in construction and impervious surfaces within the floodplain and riparian areas, has resulted in alterations to the stream's flow regime. Within agricultural areas of the watershed, intensive use of riparian areas for agricultural production has also reduced riparian vegetation.

These physical habitat alterations are closely interrelated with sedimentation. While many physical conditions directly impact available habitat, many also act through increasing erosion and sedimentation, smothering available bottom habitat. Upstream channelization and armoring also increase erosion and sedimentation by increasing flow velocities and scouring of stream bottoms and stream banks.

Because habitat alteration is not a "pollutant", a TMDL cannot be developed for this stressor. The interrelation between habitat alteration and sedimentation, however, allows the TMDL developed for sediment to address habitat alteration as well. Best management practices expected to be used in reducing sediment loads will also benefit habitat conditions. For instance, establishment of riparian vegetation reduces sediment loads from stream bank erosion and also improves habitat conditions by other means such as increasing energy inputs from leaf fall. This increases food resources for shredders and other benthic macroinvertebrates that rely on course particulate organic matter, and reduces direct sunlight that moderates stream temperatures and decreases algal growth. By implementing the sediment TMDL, it is believed that associated habitat improvements will also be achieved.

CHAPTER 5: THE REFERENCE WATERSHED MODELING APPROACH

5.1. Introduction

Because Virginia has no numeric in-stream criteria for sediment, a "reference watershed" approach was used to define allowable TMDL loading rates in the impaired watershed. The reference watershed approach pairs two watersheds - one whose streams are supportive of their designated uses and one whose streams are impaired. This TMDL reference watershed may or may not be identical to the watershed where the biological reference site was located (i.e., the site used for comparing biological metric scores). The TMDL reference watershed is selected on the basis of similarity of land use, topographical, ecological, and soils characteristics with those of the impaired watershed. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the TMDL reference watershed will result in elimination of the benthic impairment.

The reference watershed approach involves assessment of the impaired reach and its watershed; identification of potential causes of impairment through a benthic stressor analysis; selection of an appropriate TMDL reference watershed; model parameterization of the TMDL reference and impaired watersheds; definition of the target TMDL load using modeled output from the TMDL reference watershed; and development of alternative TMDL reduction (allocation) scenarios.

5.2. TMDL Reference Watershed Selection

5.2.1. Comparison of Potential Watersheds - Abrams Creek

The initial list of potential TMDL reference watersheds was composed of watersheds previously used as biological references for Abrams Creek, the two watersheds most recently used as sediment reference watersheds for the Blacks Run and Cooks Creek watersheds, and one other watershed also used as a biological reference watershed in the same region. Because sediment was identified as the pollutant responsible for the benthic impairment, the comparison of watershed characteristics focused, not only on geologic and ecologic similarities, but also on sediment-generating characteristics.

Only minor differences exist among the eco-region classifications for all of the potential TMDL reference watersheds. All of the watersheds are in the Central Appalachian Ridges and Valleys Level III ecoregion and lie predominantly in the Northern Limestone/Dolomite Valleys Level IV ecoregion. Table 5.1 compares various other physical and sediment-related characteristics of the potential TMDL reference watersheds with those of the impaired Abrams Creek watershed. The characteristics that represent sediment generation were land use distribution, average non-forested soil erodibility, and average non-forested %slope. Soil erodibility was calculated as the area-weighted average of the county level soils K-factors in each watershed.

Table 5.1. Characteristics of Potential Abrams Creek TMDL Reference Watersheds

						Non-Forested						
			Landuse Distribution			K-factor		%	meters	Year 2000 Population		
STATIONID	STREAM NAME	Area (ha)	%Urb	%For	%Agr	SSURGO	STATSGO	Slope	Elevation	Non-Sewered	Total	Non-Sewered%
ABR000.78	Abrams Creek	4,941	51%	22%	26%	0.30	0.31	6.74	235.9	10,257	29,753	34%
OPE034.53	Upper Opequon Creek	15,123	14%	28%	58%	0.31	0.30	5.60	224.1	16,322	19,809	82%
STC000.72	Strait Creek	672	0%	71%	29%	NA	0.24	18.50	988.3	57	57	100%
STY004.24	Stony Creek	19,768	1%	87%	12%	0.26	0.27	11.67	507.7	2,126	3,112	68%
BLP000.79	Bullpasture River	28,495	0%	81%	18%	NA	0.25	7.73	794.6	527	527	100%
CWP050.66	Cowpasture River	56,604	0%	86%	14%	NA	0.26	13.81	748.4	994	994	100%
HYS001.41	Hays Creek	20,801	0%	52%	48%	0.31	0.31	12.53	526.2	1,600	1,600	100%

- Impaired Watershed
- Closest Matches

5.2.2. TMDL Reference Watershed Selection - Abrams Creek

Based on the information presented in the previous section, the Upper Opequon Creek watershed was selected as the TMDL reference watershed for Abrams Creek. Land use distribution was considered the most important characteristic considered in this comparison, as the Upper Opequon is the only other predominantly agricultural watershed with a significant urban component. The other characteristics - K-factor, slope, elevation, and percent non-sewered populations - although not always the most similar available, were still quite comparable to those of Abrams Creek.

5.2.3. Comparison of Potential Watersheds - Lower Opequon Creek

The initial list of potential TMDL reference watersheds for the Lower Opequon was composed of the same watersheds used for evaluation with Abrams Creek. Because sediment was also identified as the pollutant responsible for the benthic impairment in the Lower Opequon Creek, the comparison of watershed characteristics focused, as with Abrams Creek, not only on geologic and ecologic similarities, but also on sediment-generating characteristics.

Only minor differences exist among the eco-region classifications for all of the potential reference watersheds. All watersheds are in the Central Appalachian Ridges and Valleys Level III ecoregion and lie predominantly in the Northern Limestone/Dolomite Valleys Level IV ecoregion. Table 5.2 compares various other physical and sediment-related characteristics of the TMDL reference watersheds with those of the impaired Lower Opequon Creek watershed, in a similar fashion as for the Abrams Creek watershed.

Table 5.2. Characteristics of Potential Lower Opequon Creek TMDL Reference Watersheds

						Non-Forested						
			Landuse Distribution			K-factor		%	meters	Year 2000 Population		
STATIONID	STREAM NAME	Area (ha)	%Urb	%For	%Agr	SSURGO	STATSGO	Slope	Elevation	Non-Sewered	Total	Non-Sewered%
OPE029.61	Opequon Creek	36,570	17%	31%	52%	0.31	0.31	5.29	212.7	37,997	61,569	62%
OPE034.53	Upper Opequon Creek	15,123	14%	28%	58%	0.31	0.30	5.60	224.1	16,322	19,809	82%
STC000.72	Strait Creek	672	0%	71%	29%	NA	0.24	18.50	988.3	57	57	100%
STY004.24	Stony Creek	19,768	1%	87%	12%	0.26	0.27	11.67	507.7	2,126	3,112	68%
BLP000.79	Bullpasture River	28,495	0%	81%	18%	NA	0.25	7.73	794.6	527	527	100%
CWP050.66	Cowpasture River	56,604	0%	86%	14%	NA	0.26	13.81	748.4	994	994	100%
HYS001.41	Hays Creek	20,801	0%	52%	48%	0.31	0.31	12.53	526.2	1,600	1,600	100%
JKS067.00	Jackson River	31,429	0%	81%	19%	NA	0.26	13.93	848.7	705	705	100%
QAL005.18	Quail Run	349	13%	81%	7%	0.26	0.26	10.00	452.9	8	180	4%

- Impaired Watershed
- Closest Matches

5.2.4. TMDL Reference Watershed Selection - Lower Opequon Creek

Based on the information presented in the previous section, the Upper Opequon Creek watershed was selected as the TMDL reference watershed for the Lower Opequon Creek. Land use distribution was considered the most important characteristic considered in this comparison, as the Upper Opequon is the only other watershed with a significant urban component, comprised predominantly of agricultural land uses. The other characteristics - K-factor, slope, elevation, and percent non-sewered populations - although not always the most similar available, were still quite comparable to those of the Lower Opequon Creek. Furthermore, the Upper Opequon, as a non-impaired area, upstream in the same drainage area, should also have more similarity with other more subtle characteristics as well.

5.2.5. Related Benthic Data - Upper Opequon Creek

The following limited biological monitoring had been performed at two different upstream sites on the Upper Opequon Creek which resulted in a non-impaired status for the Upper Opequon.

Table 5.3. RBP II Scores for Upper Opequon Creek

(Scores calculated against a reference watershed.)

RBP II	OPE034.53	OPE036.13
Sample Date	10/19/94	5/28/02
Samp_ID	45	2977
a. RBP II Metric Values		
Taxa Richness	17	19
MFBI	5.01	3.61
SC/CF	3.45	1.95
EPT/Chi Abund	1.95	15.66
% Dominant	18.25	25.23
Dominant Species	Planariidae	Chironomidae
EPT Index	5	12
Comm. Loss Index	0.00	0.00
SH/Tot	6.57	5.41
b. Reference Metric Values		
Station_ID	STC36	CWP2969
Reference Sample Date	10/11/94	5/6/02
Reference Sample_ID	36	2969
Taxa Richness	23	19
MFBI	3.49	3.61
SC/CF	0.74	1.95
EPT/Chi Abund	12.81	15.66
% Dominant	23.68	25.23
EPT Index	11	12
Comm. Loss Index		
SH/Tot	4.21	5.41
Reference Biological Score	46	46
c. RBP II Metric Ratios		
Taxa Richness	73.9	100.0
MFBI	69.6	100.0
SC/CF	463.8	100.0
EPT/Chi Abund	15.2	100.0
% Dominant	18.2	25.2
EPT Index	45.5	100.0
Comm. Loss Index	0.00	0.00
SH/Tot	156.0	100.0
d. RBP II Metric Scores		
Taxa Richness	4	6
MFBI	2	6
SC/CF	6	6
EPT/Chi Abund	0	6
% Dominant	6	4
EPT Index	0	6
Comm. Loss Index	6	6
SH/Tot	6	6
Total RBP II Score	30	46
% of Reference	65.22	100.00
RBP II Assessment	**Slight**	**No Impact**

Table 5.4. MAIS Assessment Results for Upper Opequon Creek

(Scores calculated against a fixed scale.)

MAIS a. MAIS Metric Values	OPE034.53	OPE036.13	Best Score Category
Sample Date	10/19/94	5/28/02	
% 5 Dominant	64.23	73.53	<79.13
MFBI	5.01	3.84	<4.22
% Haptobenthos	54.74	80.39	>83.26
EPT Index	5	8	>7
# Mayfly Taxa	3	4	>3
% Mayfly Abundance	16.06	45.10	>17.52
Simpson's Diversity Index	0.90	0.87	>0.823
# Intolerant Taxa	10	11	>9
% Scraper Abundance	43.80	48.04	>10.7
b. MAIS Scores			
% 5 Dominant	2	2	
MFBI	1	2	
% Haptobenthos	1	1	
EPT Index	1	2	
# Mayfly Taxa	1	2	
% Mayfly Abundance	1	2	
Simpson's Diversity Index	2	2	
# Intolerant Taxa	2	2	
% Scraper Abundance	2	2	
Total MAIS Score	13	17	**18**
MAIS Assessment	**Good**	**Very Good**	**Best**

Table 5.5. Habitat Evaluation for Upper Opequon Creek

Monitoring Site ID	OPE034.53	OPE036.13
Habitat Evaluation Date	10/19/94	5/28/02
HabSampID	OPE39	OPE2659
ALTER	16	19
BANKS	10	14
BANKVEG	12	20
EMBED	10	14
FLOW	18	18
RIFFLES	8	10
RIPVEG	8	13
SEDIMENT	10	10
SUBSTRATE	12	11
VELOCITY	16	16
Total Habitat Score	120	145

5.3. TMDL Modeling Target Loads

The Upper Opequon Creek watershed was used, therefore, as the TMDL reference for both Abrams Creek and the Lower Opequon Creek. The reference watershed approach was used for both Abrams Creek and the Lower Opequon Creek to define the TMDL target load as the sediment load for existing conditions from the non-impaired Upper Opequon watershed, area-adjusted separately to each of the two impaired watersheds. Reductions from various sources are specified in the alternative TMDL scenarios for each impaired watershed that achieve their respective TMDL target loads. Reductions in sediment load to the TMDL target loads are expected to allow benthic conditions to return to a non-impaired state.

CHAPTER 6: MODELING PROCESS FOR TMDL DEVELOPMENT

6.1. Source Assessment of Sediment

Sediment is generated in the Abrams Creek and Opequon Creek watersheds through the processes of surface runoff, channel and streambank erosion, and from point source inputs, as well as from background geologic forces. Natural sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, and urban land uses.

6.1.1. Surface Runoff

During runoff events, sediment loading occurs from both pervious and impervious surfaces in the watershed. For pervious areas, soil is detached by rainfall impact and transported by overland flow to nearby streams. This process is influenced by vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration, and land management practices. Dirt, dust, and fine sediment build up on impervious areas during periods without rainfall through dry deposition, which is then subject to washoff during rainfall events. Sediment generated from impervious areas can also be influenced through the use of management practices, such as street sweeping, that can reduce the surface load available to washoff.

6.1.2. Channel and Streambank Erosion

Channel erosion is the natural process of sediment movement within the stream channel, primarily during runoff events, that is accelerated by changes in hydrology within the watershed or within the stream conveyance system. Streambank erosion is caused by hydrologic factors, reduction in riparian cover, and increased human-induced activities on these areas. Animals pastured in riparian areas with access to streams often contribute to streambank erosion. The force of livestock hooves on streambanks detach clumps of soil, and push the loosened soil downslope into streams adjacent to these areas, delivering sediment to the stream independent of runoff events. Hardening of stream channels, as observed along much of Town Run, reduces upstream channel scour but increases scour downstream.

6.1.3. Point Source TSS Loads

Fine sediment is included in total suspended solids (TSS) loads that are permitted for various facilities with industrial and construction VPDES permits around the watershed. Additionally, two MS4 permits have recently been issued in the watershed. These permits are designed to reduce nonpoint source pollution of urban stormwater runoff from the MS4 areas and to compel awareness of the quality of water discharging from publicly owned storm sewer outfalls, although no numerical limits for any specific water quality parameter are stipulated in these permits. According to EPA guidance on MS4s given at http://www.deq.state.va.us/water/bmps.html ,

> "Small municipal separate storm sewer systems owners/operators must reduce pollutants in their storm water discharges to the maximum extent practicable to protect water quality. Small municipal separate storm sewer systems permits require the owner/operator to develop a storm water management program designed to prevent harmful pollutants from being washed by storm water runoff into the municipal separate storm sewer systems (or from being dumped directly into the municipal separate storm sewer systems) and then discharged from the municipal separate storm sewer systems into local waterbodies".

The MS4 permits blur the lines that have traditionally distinguished point and nonpoint sources of pollution. While the MS4 permits are regulated similarly to point source discharges, water quality discharging from the MS4s is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). Sediment loads modeled from industrial permitted dischargers, transitional (construction sites), and stormwater runoff from the MS4 areas are also included in the wasteload allocation (WLA) component of the TMDL, in compliance with 40 CFR §130.2(h). Details of the permitted dischargers are presented in Section 6.4.3.

6.2. GWLF Model Description

The Generalized Watershed Loading Functions (GWLF) model (Haith et al., 1992) was selected for comparative modeling of sediment in both of the impaired watersheds and their respective TMDL reference watersheds. GWLF is based on loading functions, which are a compromise between the simpler export coefficient models and the more complex, comprehensive water quality simulation models. GWLF is a continuous simulation, spatially-lumped parameter model that operates on a daily time step. The model is capable of simulating surface and subsurface runoff, sediment, and dissolved and attached nutrients arising from both point and non-point sources of pollution. The hydrology in the model is simulated with a daily water balance procedure among various types of storages throughout the system. Runoff is generated based on the Soil Conservation Service's Curve Number method as presented in Technical Release 55 (SCS, 1986). Erosion is generated using a modification of the Universal Soil Loss Equation. The sediment supply component uses a delivery ratio together with the erosion estimates, and sediment transport is limited by the transport capacity of the surface runoff. Channel and streambank erosion was calculated using the algorithm incorporated in an ArcView application of the GWLF model, called AVGWLF (Evans et al., 2002; Evans, 2002).

The GWLF model requires three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation. The transport file contains primarily input data related to hydrology and sediment transport, while the nutrient file contains nutrient values for the various land uses, point sources, and septic systems. The GWLF model was re-written in Visual Basic for incorporation in AVGWLF (Evans et al., 2002), and it was this version of the model that was further modified to allow for variable inputs and outputs of sediment buildup and washoff from impervious surfaces.

The following additional modifications were made to the Visual Basic version:

- Although the model simulations are hard coded to begin in April, the model was recoded to output data beginning with the following January, thus allowing summarization of results on a calendar basis.
- Urban sediment washoff was added to replace an erroneous formula that calculated USLE erosion from impervious areas.
- The groundwater flow component was modified in order to match minimum base flows estimated by the Chesapeake Bay Watershed Model for a statewide nonpoint source assessment study conducted for Virginia watersheds (Yagow et al., 2002).
- A monthly variable ET adjustment factor was added.
- A procedure was developed to automatically calculate a correction factor to account for differences between calculations of watershed total sediment yield and summations of sediment yield from individual land uses.

6.3. Input Data Requirements

6.3.1. Climatic Data

Hourly precipitation and temperature data were obtained for the two National Weather Service stations within the Opequon Creek watershed, as shown in Figure 6.1. The records for each station were edited by filling missing data and distributing missing distributions based on available records from surrounding stations. The hourly precipitation data were summed as daily totals, hourly temperature data were transformed to a daily average, and both were converted to their respective metric units (cm and °C), for use with the GWLF model. For the calibration runs, the precipitation sequences at both weather stations were compared to determine which station's precipitation produced the best correspondence with peak flows at each USGS site. The Winchester WINC station (NWS 449181) was matched with the Abrams Creek USGS gage (USGS 01616000), while the Winchester 7 SE station was matched with the Upper Opequon Creek USGS gage (USGS 01615000) for calibration. The weather data from the Winchester WINC station was used for the TMDL modeling.

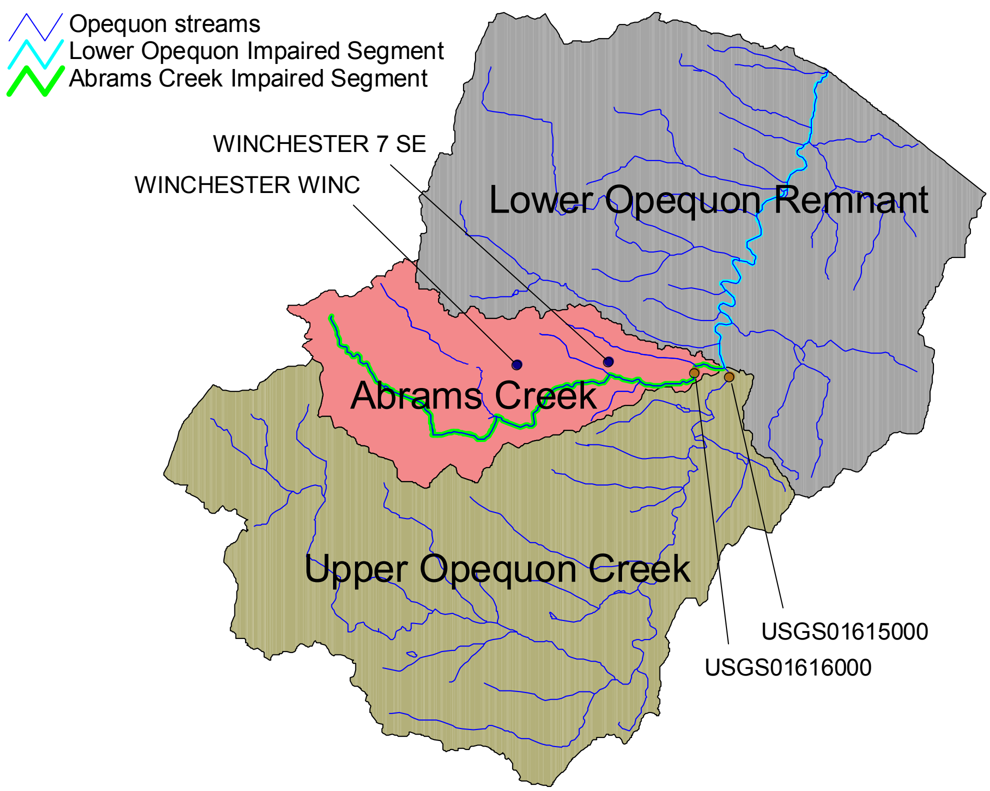

Figure 6.1. USGS Flow Gages and NWS Weather Stations in Opequon Creek

6.3.2. Land Use

A detailed digital land use layer for the entire Opequon Creek drainage area in Virginia was developed by Virginia DCR (VADCR) from digital ortho-photo quarter quads (DOQQs). Land use was consolidated into a smaller number of categories based on the differences in associated sediment sources, as shown in Table 6.1. Slightly different definitions of urban pervious/impervious percentages were used in the 2 major watersheds to adjust the curve numbers during calibration. The cropland category was further subdivided into "HiTill" and "LowTill" based on percentages assessed during the 2002 Statewide NPS Pollution Assessment study (Yagow et al., 2002). The land use categories and their distribution within the major Opequon Creek watersheds - Abrams Creek, the Upper Opequon, and the Lower Opequon Remnant - are shown in Table 6.2. Because the Lower Opequon Creek stream segment receives flow and sediment from both upstream watersheds – Abrams and Upper Opequon Creek – the entire Opequon Creek watershed was modeled to determine the sediment load in the Lower Opequon Creek impaired stream segment.

Table 6.1. Consolidated VADCR Land Use Categories in Opequon Creek

TMDL Land Use Categories	Pervious Area (percentage)	VADCR Land Use Categories
Cropland	Pervious (100%)	Cropland (211)
Pasture 1	Pervious (100%)	Improved pasture (2121)
Pasture 2	Pervious (100%)	Unimproved pasture (2122)
Pasture 3	Pervious (100%)	Overgrazed pasture (2123)
Open Urban	Pervious (100%)	Open urban (18)
Orchards	Pervious (100%)	Orchards (22)
Forest	Pervious (100%)	Forest (4)
Transitional	Pervious (100%)	Barren (7) Urban transition (16) Harvested forest (44) Confined cattle (231)
Low Density Residential (LDR)	Pervious~ (88%,85%)	LDR (111) Wooded residential (118)
Medium Density Residential (MDR)	Pervious~ (70%,65%)	MDR (112) Farmstead (241) Mobile homes (115)
High Density Residential (HDR)	Pervious~ (35%,30%)	HDR (113)
Commercial	Pervious~ (21%,15%)	Commercial (12) Industrial (13) Transportation/Utilities (14) Animal waste facility (242)

~ The percent pervious area as applied to Abrams Creek watershed and other Opequon Creek watershed areas, respectively.

Table 6.2. Existing Land Use Distributions in the Major Opequon Creek Watersheds

Land Use Category	Abrams Creek (ha)	Upper Opequon (ha)	Lower Opequon Remnant (ha)	Total (Lower) Opequon (ha)
Hi Till	19.4	455.6	529.7	1,004.6
Low Till	14.8	349.1	404.4	768.3
Pasture 1	883.2	6,139.7	8,200.2	15,223.1
Pasture 2	164.8	955.9	838.2	1,958.9
Pasture 3	0.0	31.0	53.4	84.4
Open Urban	494.5	351.4	224.0	1,069.9
Orchards	275.8	605.0	488.1	1,368.9
Forest	1,083.5	4,200.6	4,324.9	9,609.0
Transitional	48.4	105.1	101.6	255.1
LDR-pervious	65.4	267.9	399.2	732.5
MDR-pervious	629.2	481.3	143.0	1,253.4
HDR-pervious	61.0	15.2	5.2	81.4
Com-pervious	172.2	81.8	69.6	323.7
LDR-impervious	8.9	47.3	70.4	126.6
MDR-impervious	269.7	259.2	77.0	605.8
HDR-impervious	113.2	35.6	12.1	160.8
Com-impervious	648.0	463.8	394.6	1,506.4
Land Area	**4,951.9**	**14,845.3**	**16,335.6**	**36,132.9**
Water	20.62	98.05	69.60	188.27
Total Area	**4,972.5**	**14,943.3**	**16,405.2**	**36,321.1**
Major Land Use Distribution Percentages (Based on Land Area)				
Agriculture	27.4%	57.5%	64.4%	56.5%
Urban	50.7%	14.2%	9.2%	16.9%
Forest	21.9%	28.3%	26.5%	26.6%

6.3.3. Hydrologic Parameters

Hydrologic calibration was performed so that all parameters were evaluated in a consistent manner between each pair of impaired and TMDL reference watersheds. The GWLF parameter values were evaluated from a combination of GWLF user manual guidance, AVGWLF procedures, procedures developed during the statewide NPS pollutant assessment, personal judgment, and values used in the Blacks Run TMDL (Tetra Tech, 2002a). Parameters were generally evaluated using GWLF manual guidance, except where noted otherwise. All of GWLF's hydrologic and sediment parameters are included in the transport input file with the exception of urban sediment buildup rates which are in the nutrient input file. Following is a description of the various GWLF input parameters, including notations for the parameters adjusted as part of the hydrologic calibration.

Watershed-Related Parameter Descriptions

- Unsaturated Soil Moisture Capacity (SMC): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity.
- Recession coefficient (day^{-1}): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and can be approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph. (calibrated)
- Seepage coefficient (day-1): The seepage coefficient represents the amount of flow lost as seepage to deep storage. (calibrated)

The following parameters were initialized by running the model for a 9-month period prior to the selected period for which loads were calculated:

- Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.
- Initial saturated storage (cm): Initial depth of water stored in the saturated zone.
- Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.
- Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceding the first day in the weather file

Month-Related Parameter Descriptions

- Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that stored sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize sediment loads on a calendar-year basis.
- ET_CV: Composite evapo-transpiration cover coefficient, calculated as an area-weighted average from land uses within each watershed. (calibrated)
- Hours per Day: Mean number of daylight hours.

- Erosion Coefficient: This is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months of October-March, and for April-September. Values used were from the Blacks Run TMDL (Tetra Tech, 2002a).

Land Use-Related Parameter Descriptions

- Curve Number: The SCS curve number (CN) is used in calculating runoff associated with a daily rainfall event.

6.3.4. Sediment Parameters

Watershed-Related Parameter Descriptions

- Sediment delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as an inverse function of watershed size (Evans et al., 2001).

Land Use-Related Parameter Descriptions

- USLE K-factor: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- USLE LS-factor: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.
- USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession et al. (1997).
- Daily sediment buildup rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.

Channel and Streambank Erosion Parameter Descriptions

- % Developed land: percentage of the watershed with urban-related land uses.
- Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- Total upstream stream length: evaluated using GIS for individual sub-watersheds, and then summed to include upstream drainage lengths, in meters.
- Stream length with livestock access: calculated as the total stream length in the watershed where livestock have unrestricted access to streams, in meters.
- Streambank height: height of streambanks in areas with unstable channels, in meters.

6.4. Accounting for Sediment Pollutant Sources

6.4.1. Surface Runoff

Pervious area sediment loads were modeled explicitly in the GWLF using sediment detachment, a modified USLE erosion algorithm, and a sediment delivery ratio to calculate watershed loads and are reported on a monthly basis by land use. Impervious area sediment loads were modeled explicitly in GWLF using an exponential buildup-washoff algorithm.

6.4.2. Channel and Streambank Erosion

Channel and streambank erosion was modeled explicitly within GWLF using the routine included in the AVGWLF adaptation of the GWLF model (Evans et al., 2001). This routine calculates average annual channel erosion as a function of percent of developed land, average area-weighted curve number (CN) and K-factors, watershed animal density, streamflow volume, and total stream length in the watershed. An average streambank height of 1.0 m was used for the channel erosion calculations. For the future scenarios, livestock numbers and access to streams were reduced in proportion to the decreases in pasture areas in each sub-watershed.

6.4.3. Point Sources

Sediment loads from VPDES point sources under existing conditions were calculated using monthly reported Discharge Monitoring Report (DMR) data, where available. Daily loads were calculated as the monthly reported maximum daily flow times the maximum reported concentration. Average annual TSS loads were then calculated as the average of all previously calculated "daily loads" and multiplied times 365¼ days/year for each facility within the Abrams Creek watershed, as reported in Table 6.3; and within the entire Opequon Creek watershed in Table 6.4.

Since monthly DMR data is not collected for units covered under the General Permit, existing loads for these units were calculated the same as maximum permitted loads. Loads from General Permit units were calculated as the number of units in any given watershed times the maximum permitted daily flow and maximum TSS concentration allowed under this type of permit (1000 gpd and 30 mg/L). This translated into an annual TSS load of 0.0415 t/yr for each unit.

Table 6.3. Abrams Creek - Existing TSS Loads from Permitted Dischargers

VPDES ID	Name	DMR Maximum Daily Flow (MGD)	DMR Maximum Daily [TSS] (mg/L)	Existing Annual Load (t/yr)
VA0002739	Perry, S. M.[1]	0.09900	3.00	0.410
VA0051373	National Fruit[1]	0.03200	5.00	0.221
VA0076384	Abex[1]	0.21470	3.06	0.909
0 - Single Family General Permit 1000 gpd Units[2]		0.001	30	0.000
VAR040053	City of Winchester[3]			527.0
VAR040032	VDOT - Winchester Urban Area[3]			
Existing TSS Load From Permitted Dischargers				**528.5**

[1] The existing TSS load from permitted dischargers is calculated from the average of all monthly reported maximum daily flow and maximum daily concentration.
[2] General Permit Loads are calculated as the number of units (0) multiplied by the maximum daily flow (1000 gpd) and the maximum TSS concentration (30 mg/L).
[3] Existing loads in MS4 areas are calculated as the modeled loads from urban transitional and impervious areas within the City limits.

Table 6.4. Opequon Creek - Existing TSS Loads from Permitted Dischargers

VPDES ID	Name	DMR Maximum Daily Flow (MGD)	DMR Maximum Daily [TSS]	Existing Annual Load (t/yr)
VA0002739	Perry, S. M.[1]	0.09900	3.00	0.410
VA0023116	I-81 Rest Area STP[1]	0.00500	8.89	0.061
VA0027600	A & K Car Wash[1]	0.00100	23.09	0.032
VA0029653	Shalom et Benedictus Lagoon[1]	0.00300	19.32	0.080
VA0051373	National Fruit[1]	0.03200	5.00	0.221
VA0065552	Opequon Regional AWT[1]	4.80000	2.96	19.618
VA0075191	Parkins Mill STP[1]	1.21500	3.18	5.342
VA0076384	Abex[1]	0.21470	3.06	0.909
VA0088471	Frederick Co. Landfill[1]	0.14200	15.13	2.968
VA0088722	Stonebrook Swim Club[1]	0.00087	2.61	0.003
VA0089010	Franciscan Center[1]	0.00013	4.40	0.001
VA0090808	APAC Virginia WWTP[1]			
45 - Single Family General Permit 1000 gpd Units[2]		0.001	30	1.865
VAR040053	City of Winchester[3]			336.2
VAR040032	VDOT - Winchester Urban Area[3]			
Existing TSS Load From Permitted Dischargers				**367.7**

[1] The existing TSS load from permitted dischargers is calculated from the average of all monthly reported maximum daily flow and maximum daily concentration.
[2] General Permit Loads are calculated as the number of units (45) multiplied by the maximum daily flow (1000 gpd) and the maximum TSS concentration (30 mg/L).
[3] Existing loads in MS4 areas are calculated as the modeled loads from urban transitional and impervious areas within the City limits.

Sediment loads related to stormwater runoff from areas covered by MS4 permits (City of Winchester - VAR040053; VDOT-Winchester Urban Area - VAR040032) were modeled with

GWLF as contributions from transitional (construction sites) and impervious land use categories within the city boundary. Existing loads for the MS4 permits were calculated in aggregate within the portion of the City of Winchester that lies in each watershed, as showqn in Table 6.5. MS4 loads from Abrams Creek that were counted in the Lower Opequon were reduced by applying a ratio (0.55) to account for the different upstream drainage areas in the two watersheds used in calculating watershed sediment delivery ratios. Sediment loads from both VPDES and 1000 gpd facilities, and reductions to the downstream MS4 loads, were all calculated in a spreadsheet outside of the GWLF model for summarizing GWLF model outputs.

Table 6.5. MS4 Areas Within Opequon Creek Subwatersheds

	Abrams Creek Subwatersheds						**Abrams Creek Total**	**Redbud Run 200**	**Upper Opequon 400**	**MS4 Total**
	301	**302**	**303**	**304**	**305**	**306**				
Impervious Area	220.7	172.3	126.7	118.3	159.8	46.4	844.1	116.073	743.3	
Impervious Area in MS4	35.2	39.7	126.0	107.8	153.5	12.9	475.1	13.9	70.2	**559.2**
% Impervious Area in MS4	16.0%	23.0%	99.5%	91.1%	96.1%	27.9%	56.3%	12.0%	9.4%	
Transitional Area	4.1	4.3	0.0	0.0	11.1	28.7	48.3	2.610	101.1	
Transitional Area in MS4	0.0	0.3	0.0	0.0	11.1	0.0	11.5	0.0	0.0	**11.5**
%Transitional Area in MS4	0.0%	7.7%	0.0%	0.0%	100.0%	0.0%	23.7%	0.0%	0.0%	

All areas are given in hectares.

6.4.4. Accounting for Existing BMPs

After modeling was performed on individual and cumulative sub-watersheds, and total watersheds, the model output was post-processed in an Excel spreadsheet to distill the modeling results and to account for existing agricultural best management practices (BMPs) within the various sub-watersheds of Opequon Creek.

The effect of installed agricultural BMPs was based on the Virginia Department of Conservation and Recreation's State Cost-Share Database. This database tracks the implementation of BMPs within each state HUP watershed. These data are then used by EPA's Chesapeake Bay Program to calculate sediment reduction and pass-through fractions of the sediment load from each land use in each HUP for use with the Chesapeake Bay model and with the Virginia 2002 Statewide NPS Pollution Assessment (Yagow et al., 2002). The modeled land use categories used for this TMDL study were each related to, and assigned values from, one of the land use categories from the Statewide assessment. Modeled sediment loads within each land use category were then multiplied by their respective pass-through fractions to simulate the reduced loads resulting from existing BMPs. Details of the BMP accounting are provided in Appendix D.

6.5. Accounting for Critical Conditions and Seasonal Variations

6.5.1. Critical Conditions

The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The period of rainfall selected for modeling was chosen as a multi-year period that was representative of typical weather conditions for the area, and included “dry”, “normal” and “wet” years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow, generally associated with point source loads, and critical conditions during high flow, generally associated with nonpoint source and channel erosion loads.

6.5.2. Seasonal Variability

Seasonal variation was incorporated in the modeling process through a number of mechanisms within the GWLF model. Daily time steps are included in the model for weather data input and water balance calculations. The model also allows for monthly-variable inputs for evapotranspiration cover coefficients, daylight hours/day, and rainfall erosivity coefficients for user-specified growing season months.

6.6. Model Calibration for Hydrology

The GWLF model was originally developed for use in ungaged watersheds (Haith et al., 1992). However, the BasinSim adaptation of the model (Dai et al., 2000) recommends hydrologic calibration of the model, and preliminary calibrated model results for the gaged Linville Creek watershed in a previous TMDL study (Mostaghimi et al., 2003) showed an 18% reduction in the percent error between simulated and observed monthly runoff. Since observed daily flow data were available at both Abrams Creek and its TMDL reference watershed - Upper Opequon Creek - hydrologic calibration was performed on both watersheds. Since GWLF was used to compare the simulation results between the target and its TMDL reference watershed, both watersheds were calibrated in a similar manner without dividing them into sub-watersheds.

The purpose of calibration is to adjust parameter values within the model so that simulated model output more closely matches observed data. The reason for performing the hydrologic calibration is to enable simulation of the hydrology-dependent components as accurately as possible. The purpose of calibration for the reference watershed approach is to provide a more representative total flow and flow distribution on which to base sediment loading.

The National Weather Service (NWS) has a much denser network of rainfall gaging stations than the U.S. Geological Survey (USGS) has for recording daily flow. Therefore, in any calibration effort, flow data are generally the limiting factor. Fortunately, USGS flow gages are located near the outlets of both the Abrams and the Upper Opequon Creek watersheds. Daily observed flow measurements were obtained for both stations and compared with GWLF model output. Figure 6.1 shows the location of both the USGS flow gages and NWS precipitation gages in relation to each watershed. Table 6.6 shows the available period of record for each station.

Table 6.6. Available USGS Daily Flow Data

Watershed	USGS #	Daily Flow Record
Abrams Creek	01616000	07-27-1949 to 11-14-1997
Upper Opequon Creek	01615000	10-01-1943 to 10-17-1997

The period - April 1981 through December 1987 – was chosen as both the calibration and TMDL modeling period. This period was chosen from within the common record for both stations, to include a wide range of rainfall conditions, and to avoid overlapping 1988, when STP discharge was diverted outside of the watershed. The first 9 months of data were used for initialization of storage parameters within the model, with 6 years of simulated output compared with the observed record at each station.

GWLF requires daily rainfall inputs and generates monthly runoff outputs. Hydrologic calibration was performed by comparing simulated and observed monthly runoff (flow) totals. GWLF can produce outputs of monthly surface runoff by land use, as well as monthly groundwater flow, assumed to represent the baseflow component. Calibration was performed to match simulated and observed total flow and seasonal distributions. The USGS software program HYSEP (Sloto and Crouse, 1996) was used to estimate the percentage of baseflow for each watershed, as summarized in Table 6.7, using the local minimum option. An initial attempt to calibrate the monthly baseflow% was abandoned, however, as calibration of surface runoff curve numbers was determined to be inappropriate.

Table 6.7. Baseflow as Percentage of Total Streamflow (using HYSEP for baseflow separation)

Watershed	USGS #	Period Assessed	Monthly Baseflow %		
			Min	Mean	Max
Abrams Creek	01616000	Jan 1980 – Dec 1993	72.0	78.4	85.1
Upper Opequon Creek	01615000	Jan 1980 – Dec 1993	36.7	49.6	77.8

Spreadsheets were constructed to analyze model output after each model run, and to calculate parameter adjustments for the next iteration of calibration. Within the spreadsheets, comparisons were made between simulated and observed runoff for the flow components, seasonal distribution, monthly runoff time series, and cumulative runoff. Surface runoff was adjusted slightly through a re-evaluation of cover conditions relevant to each land use category, and the pervious/impervious split for the various urban uses. Total flow and seasonal distributions were calibrated through adjustments to the minimum and maximum evapo-transpiration (ET) cover coefficients, and the recession and seepage coefficients.

The results of the hydrologic calibration for Abrams Creek are presented as the monthly runoff time series in Figure 6.2 and cumulative runoff in Figure 6.3, along with the flow and seasonal distributions in Table 6.8. The corresponding results for Upper Opequon Creek are presented in Figures 6.4 and 6.5, and Table 6.9.

The monthly runoff time series for Abrams showed a generally good correspondence between observed and simulated monthly runoff, with a correlation coefficient of 0.873. Total simulated runoff was 1.8% less than the observed value. The simulated percentages of runoff distributed among seasons were all within 10% of observed values, with the exception of fall runoff. This difference was traced to a mismatch of precipitation and observed flow increases during October 1986. The difference between observed and simulated individual seasonal average annual runoff totals were less than or equal to ±1.2cm/yr.

The monthly runoff time series for Upper Opequon also showed a generally good correspondence between observed and simulated monthly runoff, with a correlation coefficient of 0.923. Total simulated runoff was only 0.9% more than the observed value. The simulated distributions of runoff among seasons were all within 5% of observed values. The difference between observed and simulated individual seasonal average annual runoff totals were less than or equal to ±0.6 cm/yr.

In summary, correlation between simulated and observed total runoff were quite good with correlation coefficients of 87% or greater. Cumulative total monthly runoff over the 6-year period was within 1.8% of observed totals. A slightly larger variability was seen in the distribution among seasons, although even these were mostly within 10%. Part of these differences can be explained by the expected variability between measurements at a single precipitation station and how rainfall is actually distributed over an entire watershed. The major part of the differences, however, relate to the fact that the GWLF model is a daily time-step, lumped parameter model. As such, it is not expected to replicate all flow regimes and seasonal distributions consistently under all conditions. However, since the reference watershed approach uses average loading over long periods and utilizes comparably parameterized and calibrated watersheds, the calibrated GWLF model is considered suitable for reasonable load comparisons for development of a TMDL. Observed flow data for the Lower Opequon was not available for performing a hydrologic calibration. However, both Abrams Creek and the Upper Opequon watersheds are part of the overall Opequon watershed, and since they were both calibrated, area-weighted calibration parameters were calculated and applied to the Lower Opequon Remnant.

A complete listing of all GWLF parameter values evaluated for the GWLF transport file for both watersheds during hydrologic calibration of existing conditions are shown in Tables 6.10 - 6.13. Table 6.10 lists the various watershed-wide parameters and their values, Table 6.11 displays the monthly composite evapo-transpiration cover coefficients, Table 6.12 shows the land use-related parameters – runoff curve numbers (CN) and the Universal Soil Loss Equation's KLSCP quotient for erosion modeling, and Table 6.13 shows the results of area adjustments made to the respective TMDL reference watersheds.

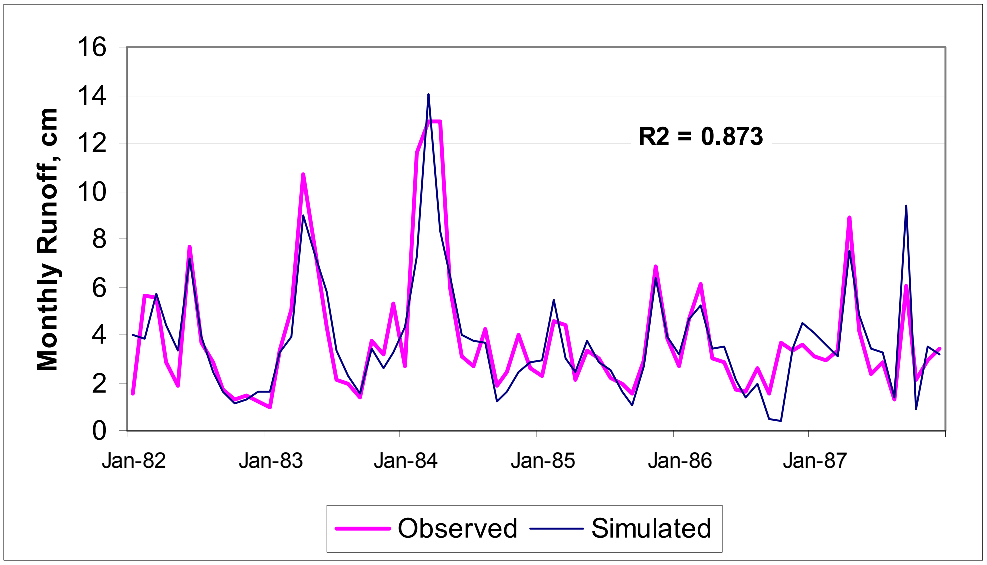

Figure 6.2. Calibration Monthly Runoff Time Series – Abrams Creek

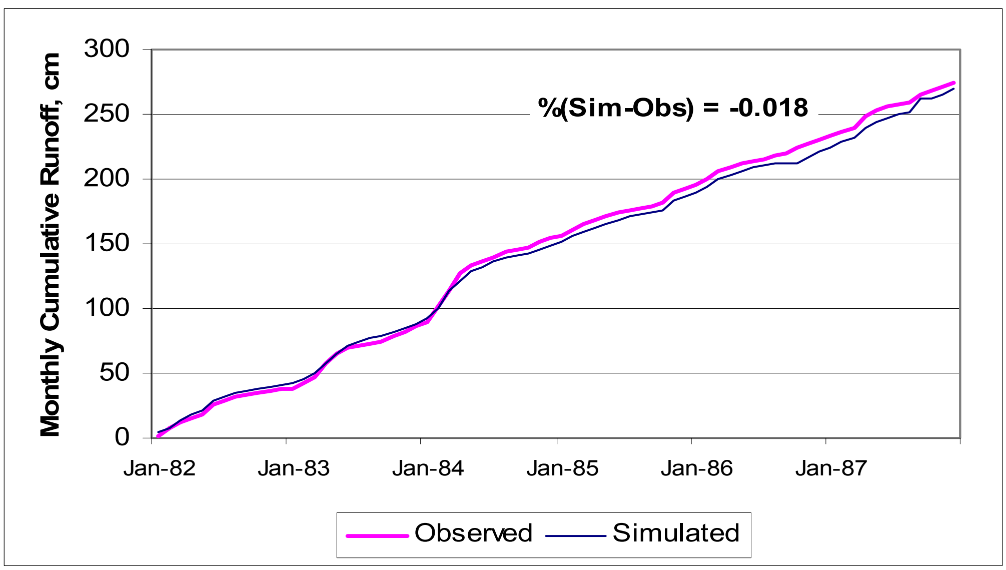

Figure 6.3. Calibration Cumulative Runoff – Abrams Creek

Table 6.8. Calibration Flow Distributions – Abrams Creek – 1982-1987

Flow Distribution Components	SIMULATED		OBSERVED		Sim-Obs	
	(cm/yr)	(% of Total)	(cm/yr)	(% of Total)	(cm/yr)	(% of Total)
Total Runoff	44.84		45.66		-0.83	-1.8%
Total Surface Runoff	17.05	38.0%	10.24	22.4%	6.81	66.6%
Total Baseflow	27.78	62.0%	35.43	77.6%	-7.64	-21.6%
Winter (Dec-Feb) Runoff	11.26	25.1%	10.98	24.1%	0.27	2.5%
Spring (Mar-May) Runoff	16.55	36.9%	17.26	37.8%	-0.72	-4.2%
Summer (Jun-Aug) Runoff	9.51	21.2%	8.71	19.1%	0.80	9.2%
Fall (Sep-Nov) Runoff	7.53	16.8%	8.71	19.1%	-1.18	-13.6%

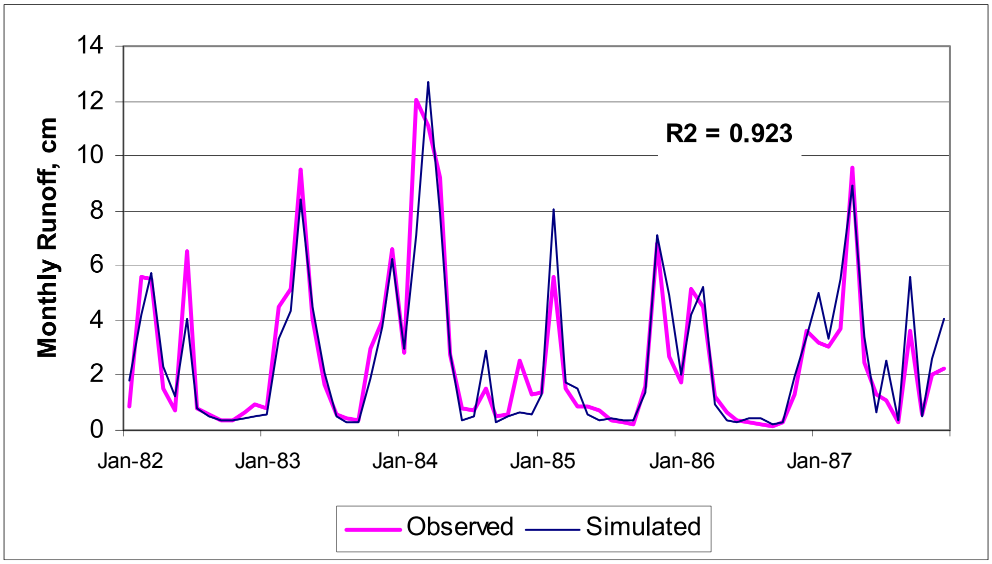

Figure 6.4. Calibration Monthly Runoff Time Series - Upper Opequon Creek

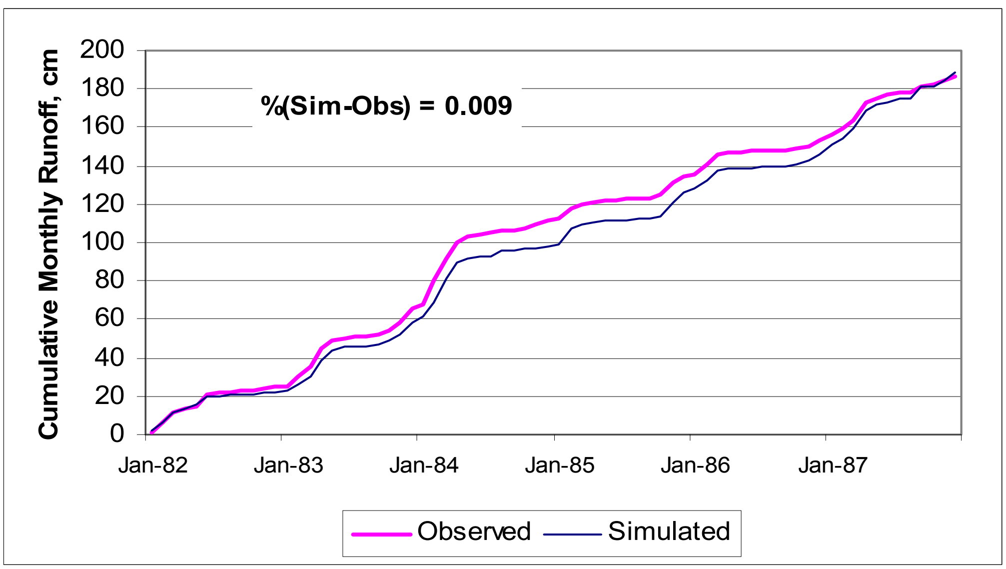

Figure 6.5. Calibration Cumulative Runoff - Upper Opequon Creek

Table 6.9. Calibration Flow Distributions - Upper Opequon Creek

Flow Distribution Components	SIMULATED (cm/yr)	SIMULATED (% of Total)	OBSERVED (cm/yr)	OBSERVED (% of Total)	Sim-Obs (cm/yr)	Sim-Obs (% of Total)
Total Runoff	31.35		31.07		0.28	0.9%
Total Surface Runoff	10.05	32.1%	17.59	56.6%	-7.54	-42.8%
Total Baseflow	21.30	67.9%	13.48	43.4%	7.81	58.0%
Winter (Dec-Feb) Runoff	10.62	33.9%	10.69	34.4%	-0.07	-0.7%
Spring (Mar-May) Runoff	13.02	41.5%	12.46	40.1%	0.57	4.5%
Summer (Jun-Aug) Runoff	2.95	9.4%	3.10	10.0%	-0.15	-4.8%
Fall (Sep-Nov) Runoff	4.76	15.2%	4.82	15.5%	-0.07	-1.4%

Table 6.10. GWLF Watershed Parameters – Existing Conditions

GWLF Watershed Parameters	units	Abrams Creek	Upper Opequon	Lower Opequon Remnant
recession coefficient	(day^{-1})	0.0140	0.0600	0.0537
seepage coefficient	(day^{-1})	0.0000	0.0250	0.0216
sediment delivery ratio		0.1409	0.1018	0.0781
unsaturated water capacity	(cm)	16.21	13.94	14.34
erosivity coefficient (Nov - Apr)		0.1	0.1	0.1
erosivity coefficient (growing season)		0.3	0.3	0.3
% developed land	(%)	38.4	9.3	11.2
no. of livestock	(AU)	225	1090	4130
area-weighted soil erodibility		0.297	0.298	0.297
area-weighted runoff curve number		79.76	76.02	76.29
total stream length **	(m)	29,956.5	110,550.7	257,667.4
stream length with livestock access	(m)	2,372.9	33,393.9	42,492.4

** total stream length was reduced by the length of channelized sections of the stream for the purposes of estimating channel erosion.

Table 6.11. GWLF Monthly Evapotranspiration Cover Coefficients – Existing Conditions

Watershed	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
Abrams Creek	0.700	0.708	0.710	**0.710**	0.710	0.702	0.646	0.590	0.566	**0.550**	0.630	0.684
Upper Opequon	0.938	0.947	0.950	**0.950**	0.950	0.940	0.870	0.800	0.770	**0.750**	0.850	0.918
Lower Opequon Remnant	0.965	0.978	0.982	**0.982**	0.982	0.968	0.869	0.770	0.728	**0.700**	0.841	0.937

* July values represent the maximum composite ET coefficients during the growing season.

** January values represent the minimum composite ET coefficients during dormancy.

Table 6.12. GWLF Land Use Parameters – Existing Conditions

Landuse	Abrams Creek		Upper Opequon		Lower Opequon Remnant	
	KLSCP	CN	KLSCP	CN	KLSCP	CN
Hi Till	1.0708	86.39	0.5628	86.12	0.3876	86.18
Low Till	0.4673	84.50	0.2412	84.21	0.1678	84.30
Pastue 1	0.0097	74.02	0.0066	73.40	0.0052	73.61
Pasture 2	0.0318	79.04	0.0258	78.51	0.0187	78.70
Pasture 3	0.0000	85.99	0.0817	85.66	0.0980	85.78
Open Urban	0.0297	78.08	0.0285	77.76	0.0133	77.80
Orchards	0.0036	76.09	0.0023	75.55	0.0025	75.71
Forest	0.0016	73.02	0.0017	72.34	0.0012	72.60
Transitional	0.4644	91.06	0.5114	90.87	0.1611	90.90
LDR-pervious	0.0091	74.02	0.0078	78.51	0.0075	78.70
MDR-pervious	0.0070	74.02	0.0056	78.51	0.0047	78.70
HDR-pervious	0.0074	74.02	0.0029	78.51	0.0009	78.70
Com-pervious	0.0074	74.02	0.0064	78.51	0.0041	78.70
LDR-impervious	0.0000	91.97	0.0000	91.77	0.0000	91.88
MDR-impervious	0.0000	98.00	0.0000	98.00	0.0000	98.00
HDR-impervious	0.0000	98.00	0.0000	98.00	0.0000	98.00
Com-impervious	0.0000	98.00	0.0000	98.00	0.0000	98.00

Table 6.13. Area Adjustments to TMDL Reference Watersheds (ha)

Land Use Category	Abrams Creek TMDL			Lower Opequon Creek TMDL		
	Impaired		**Reference**	**Impaired**		**Reference**
	Abrams Creek	Upper Opequon	**Upper Opequon (x 0.334)**	**Opequon Creek**	Upper Opequon	**Upper Opequon (x 2.434)**
Hi Till	19.4	455.6	152.0	1,004.6	455.6	1,108.8
Low Till	14.8	349.1	116.4	768.3	349.1	849.7
Pasture 1	883.2	6,139.7	2,048.0	15,223.1	6,139.7	14,943.8
Pasture 2	164.8	955.9	318.8	1,958.9	955.9	2,326.6
Pasture 3	0.0	31.0	10.3	84.4	31.0	75.5
Open Urban	494.5	351.4	117.2	1,069.9	351.4	855.3
Orchards	275.8	605.0	201.8	1,368.9	605.0	1,472.5
Forest	1,083.5	4,200.6	1,401.2	9,609.0	4,200.6	10,224.0
Transitional	48.4	105.1	35.1	255.1	105.1	255.9
LDR-pervious	65.4	267.9	89.4	732.5	267.9	652.0
MDR-pervious	629.2	481.3	160.5	1,253.4	481.3	1,171.4
HDR-pervious	61.0	15.2	5.1	81.4	15.2	37.1
Com-pervious	172.2	81.8	27.3	323.7	81.8	199.2
LDR-impervious	8.9	47.3	15.8	126.6	47.3	115.1
MDR-impervious	269.7	259.2	86.4	605.8	259.2	630.8
HDR-impervious	113.2	35.6	11.9	160.8	35.6	86.5
Com-impervious	648.0	463.8	154.7	1,506.4	463.8	1,128.8
Total Land Area	**4,951.9**	**14,845.3**	**4,951.9**	**36,132.9**	**14,845.3**	**36,132.9**

CHAPTER 7: THE BENTHIC TMDLS FOR SEDIMENT

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

7.1. Background

The benthic TMDL using sediment was developed for each impaired stream segment using a reference watershed approach. The GWLF model was calibrated for hydrology and then run for existing conditions over the 6-yr period of January 1982 – December 1987. The average annual sediment load (t/yr) from the TMDL reference watershed, area-adjusted to each impaired watershed, was used to define the TMDL sediment load for the respective impaired watersheds.

In order to provide more information on the spatial variability of the sediment loads for the implementation phase, the entire Opequon Creek watershed was subdivided into 9 sub-watersheds, as shown in Figure 7.1. Modeling was performed on these 9 sub-watersheds plus the 2 area-adjusted versions of the reference watershed.

Of the 9 sub-watersheds in the Opequon Creek watershed, 4 sub-watersheds – 200, 304, 306, and 400 originate with headwater segments, while the remaining 5 downstream sub-watersheds receive flow and sediment from one or more upstream sub-watersheds. Because the GWLF model was not designed to model downstream sub-watersheds independently, each watershed was modeled to include all of its upstream drainage. Spreadsheet accounting was then used to subtract loads from upstream segments and to account for differences in the GWLF area-based sediment delivery ratio parameter for the two watersheds, thereby apportioning watershed sediment loads among the various sub-watersheds. In order to focus on the comparison between the impaired and reference watersheds, all loads in the following discussion are reported only as totals for each of the impaired watersheds and their area-adjusted TMDL reference. Details on model parameter inputs and sediment loads for all of the individual sub-watersheds are given in Appendix C.

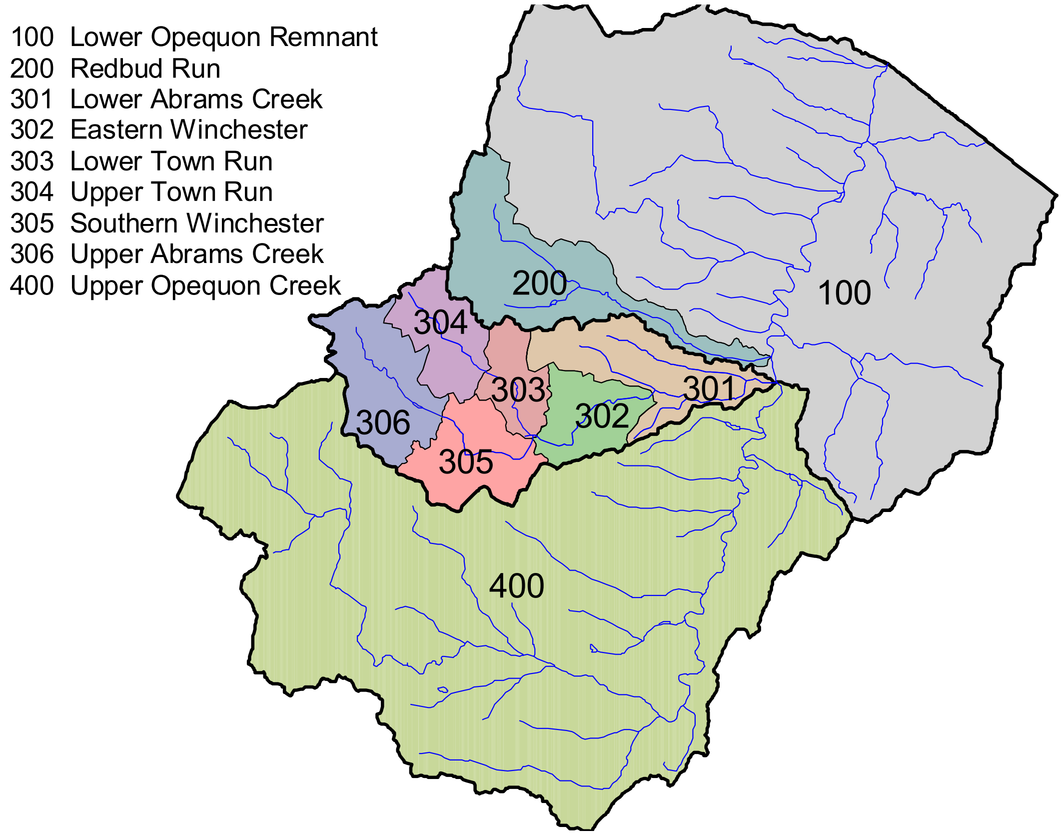

Figure 7.1. GWLF Modeling Sub-watersheds for Opequon Creek

7.2. The Abrams Creek Benthic TMDL

The benthic TMDL for the Abrams Creek watershed was developed using sediment as the pollutant and a reference watershed approach, with the Upper Opequon Creek watershed as the TMDL reference watershed. Since the Upper Opequon Creek watershed was larger than Abrams Creek, the area of each land use in the Upper Opequon watershed was reduced in proportion to the ratio of the area of the impaired watershed to that of the TMDL reference watershed (x 0.334), as detailed in Table 6.13. This resulted in an area-adjusted Upper Opequon watershed equal in size with the land area in the impaired Abrams Creek watershed (4,952 ha).

7.2.1. Existing Loads and the Target TMDL Sediment Load

The existing sediment loads were modeled for each watershed and are listed in Table 7.1 by sediment source as average annual (t/yr) and unit-area (t/ha) loads. The target TMDL sediment load in Abrams Creek - 6,327.3 t/yr - was defined as the average annual sediment load for the area-adjusted Upper Opequon Creek watershed under existing conditions.

Table 7.1. Abrams Creek TMDL - Existing Sediment Loads (t/yr)

	Abrams Creek			Area-adjusted Upper Opequon Creek		
Sediment Sources	**(t/yr)**	**(%)**	**(t/ha)**	**(t/yr)**	**(%)**	**(t/ha)**
High Till	764.8	8.6%	39.48	2,362.7	37.3%	15.55
Low Till	253.9	2.9%	17.17	1,056.9	16.7%	9.08
Pasture	320.1	3.6%	0.31	561.6	8.9%	0.24
Urban grasses	441.3	5.0%	0.89	97.9	1.5%	0.83
Orchards	24.8	0.3%	0.09	12.2	0.2%	0.06
Forest	36.1	0.4%	0.03	50.0	0.8%	0.04
Transitional	452.8	5.1%	9.36	504.7	8.0%	14.39
Pervious Urban	146.3	1.6%	0.16	46.3	0.7%	0.16
Impervious Urban	290.5	3.3%	0.28	167.5	2.6%	0.62
MS4	527.0	5.9%		0.0	0.0%	
Other Permitted Point Sources	1.5	0.0%		3.0	0.0%	
Channel Erosion	5,648.3	63.4%	1.14	1,464.5	23.1%	0.30
Watershed Totals	**8,907.4**	100.0%		**6,327.3**	100.0%	
			Target Sediment TMDL Load =	**6,327**		**t/yr**
			10% MOS =	633		t/yr
			Load for Allocation =	**5,695**		**t/yr**

The benthic TMDL for Abrams Creek is comprised of three required sediment load components - the waste load allocation (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), as shown in Table 7.2.

Table 7.2. Abrams Creek TMDL Sediment Goal (t/yr)

TMDL	WLA	LA	MOS
6,327.3	470.1	5,224.4	632.7

The margin of safety (MOS) was explicitly defined as 10% of the calculated TMDL to reflect the relative uncertainty associated with benthic impairments. The waste load allocation (WLA) was calculated as the sum of all permitted TSS loads, as detailed in Table 7.3. The load allocation (LA) - the allowable sediment load from nonpoint sources - was calculated as the target TMDL load minus the MOS minus the WLA. Since the MOS is excluded from allocation, the target load for modeling purposes in Abrams Creek becomes the TMDL minus the MOS (5,695 t/yr).

Table 7.3. Abrams Creek TMDL Sediment WLA Allocations (t/yr)

VPDES ID	Name	Permitted Design Flow (MGD)	Permitted Monthly Ave Conc (mg/L)	WLA (t/yr)
VA0002739	Perry, S. M.[1]	0.10	30	4.15
VA0051373	National Fruit[1]	0.06	30	2.49
VA0076384	Abex[1]	0.50	30	20.73
0 - Single Family General Permit 1000 gpd Units[2]		0.001	30	0.00
VAR040053	City of Winchester[3]			442.7
VAR040032	VDOT - Winchester Urban Area[3]			
WLA Total				**470.1**

[1] WLA was calculated from the permitted design flow and the permitted monthly average concentration.

[2] General Permit Loads are calculated as the number of units (0) multiplied by the maximum daily flow (1000 gpd) and the maximum TSS concentration (30 mg/L).

[3] MS4 loads were assigned in aggregate based on the allocation reductions to the modeled loads from urban transitional and impervious areas within the watershed and inside City limits.

7.2.2. TMDL Allocation Scenarios

Because of expected future growth in the watershed, TMDL modeling scenarios were run for varying levels of build-out within Frederick County's Urban Designated Areas (UDAs) and Commercial Center (ComCntrs) planning zones within the Opequon Creek watershed, as shown in Table 7.4. Based on growth rates seen in other urbanizing rural areas, the 25% Buildout option was selected as most appropriate. The increases in MS4 load are based on the increase in transitional and impervious urban areas as described in Section 3.6, and listed in Appendix B. The increase in the other Permitted Point Sources was due to basing future loads for each permitted facility on its permitted design flow and maximum daily average TSS concentration rather than on reported monthly DMR data, as in the existing scenario.

Table 7.4. Abrams Creek Projected Future Sediment Loads (t/yr)

Sediment Sources	% BuildOut within UDAs and ComCntrs 25% (t/yr)	50% (t/yr)	100% (t/yr)
High Till	736	707	649
Low Till	244	235	215
Pasture	266	211	103
Urban grasses	441	441	441
Orchards	23	22	19
Forest	30	23	11
Transitional	454	455	457
Pervious Urban	174	202	258
Impervious Urban	345	400	509
MS4	590	654	781
Other Permitted Point Sources	27	27	27
Channel Erosion	6,620	7,589	9,489
Watershed Totals	**9,950**	**10,965**	**12,958**

The reductions required to meet the TMDL from existing and future conditions based on the 25% Buildout scenario will need to be made to the target modeling load, as summarized in Table 7.5.

Table 7.5. Summary of Required Reductions for Abrams Creek

Load Summary	(t/yr)	Reductions Required (t/yr)	(% of Existing Load)
Projected Future Load	9,950	4,256	47.8%
Existing Load	8,907	3,213	36.1%
TMDL	6,327		
Target Modeling Load (TMDL-MOS)	5,695		

TMDL allocation scenarios were developed by consolidating nonpoint source loads into 3 categories - agriculture, urban, and forestry - and then comparing category loads from the Abrams Creek watershed to those of its area-adjusted reference in Table 7.6. “Urban” and MS4 loads were generated as one land use category in the model, but they were separated during the spreadsheet post-processing, since MS4 loads are required to be included in the WLA portion of the TMDL. The comparison in Table 7.6 shows that the annual average sediment loads from agriculture and forestry are already lower from Abrams Creek than from its reference, so no reductions were required from them. Reductions were also not required from individual point sources because they contribute <1% of the total load.

Table 7.6. Categorized Sediment Loads for Abrams Creek (t/yr)

Source Category	Future25 Abrams Creek (t/yr)	TMDL Target Area Adjusted Upper Opequon (t/yr)
Agriculture	1,269.0	3,993.5
Urban	1,414.2	816.3
Forestry	29.7	50.0
Channel Erosion	6,619.9	1,464.5
MS4	590.3	0.0
Point Sources	27.4	3.0
Total	**9,950.5**	**6,327.3**

The remaining land use categories - "urban" and "channel erosion" - therefore, are the two major categories from which reductions can be obtained. The three alternative TMDL allocation scenarios shown in Table 7.7 were developed by taking varying percentages of reductions from these two categories with a smaller fixed load from "agriculture" to account for streambank stabilization needed to complement the reductions required from channel erosion. Varying levels of sediment reduction in the allocation scenarios were also required from implementation of BMPs in MS4 permitted areas, with equal reductions from the "urban" category. The recommended TMDL allocation scenario is Alternative 3, as it balances the probable greater cost of obtaining reductions from urban areas, with the probability of obtaining greater reductions from the largest source category – "channel erosion".

Table 7.7. TMDL Allocation Scenarios for Abrams Creek

Source Category	Future25 Abrams Creek (t/yr)	Abrams Creek TMDL Sediment Load Allocations					
		TMDL Alternative 1		TMDL Alternative 2		TMDL Alternative 3	
		(% reduction)	(t/yr)	(% reduction)	(t/yr)	(% reduction)	(t/yr)
Agriculture	1,269	**10%**	1,142	**10%**	1,142	**10%**	1,142
Urban	1,414	0%	1,414	**47.9%**	737	**25%**	1,061
Forestry	30	0%	30	0%	30	0%	30
Channel Erosion	6,620	**62.4%**	2,491	**47.9%**	3,451	**54.8%**	2,992
MS4*	590	0%	590	**47.9%**	308	**25%**	443
Point Sources	27	0%	27	0%	27	0%	27
Total	**9,950**		**5,695**		**5,695**		**5,695**

* Percent reductions in loads from MS4 areas were assumed equal to those from all Urban sources.

7.3. The Lower Opequon Creek Benthic TMDL

The benthic TMDL for the Lower Opequon Creek watershed was developed using sediment as the target pollutant and a reference watershed approach, with the Upper Opequon Creek watershed as the TMDL reference watershed. The loads to the impaired Lower Opequon Creek stream segment arise not only from the Lower Opequon Remnant, but from the Abrams Creek and the Upper Opequon Creek watersheds as well. Therefore the entire Opequon Creek watershed was modeled to generate loads to the Lower Opequon Creek segment, and was considered to be the impaired watershed. Since the Upper Opequon Creek watershed was smaller than the entire Opequon Creek watershed, the area of each land use in the Upper Opequon watershed was increased in proportion to the ratio of the area of the impaired watershed to that of the TMDL reference watershed (x 2.434), as detailed earlier in Table 6.13. This resulted in an area-adjusted Upper Opequon watershed equal in size with the land area in the impaired Lower Opequon Creek watershed (36,133 ha).

7.3.1. Existing Loads and the Target TMDL Sediment Load

The existing sediment loads were modeled for each watershed and are listed in Table 7.8 by sediment source as average annual (t/yr) and unit-area (t/ha) loads. The target TMDL sediment load for Opequon Creek – 53,761.4 t/yr - was defined as the average annual sediment load from the area-adjusted Upper Opequon Creek watershed under existing conditions.

Table 7.8. Lower Opequon Creek TMDL - Existing Sediment Loads (t/yr)

	Opequon Creek			Area-adjusted Upper Opequon Creek		
Sediment Sources	**(t/yr)**	**(%)**	**(t/ha)**	**(t/yr)**	**(%)**	**(t/ha)**
High Till	8,690.5	15.1%	8.65	9,605.9	17.9%	8.66
Low Till	2,868.7	5.0%	3.73	3,323.6	6.2%	3.91
Pasture	1,964.9	3.4%	0.11	2,092.2	3.9%	0.12
Urban grasses	532.1	0.9%	0.50	425.4	0.8%	0.50
Orchards	50.4	0.1%	0.04	54.2	0.1%	0.04
Forest	93.4	0.2%	0.01	172.0	0.3%	0.02
Transitional	1,657.7	2.9%	6.50	1,314.6	2.4%	5.14
Pervious Urban	239.8	0.4%	0.10	205.3	0.4%	0.10
Impervious Urban	1,153.1	2.0%	0.48	1,222.0	2.3%	0.62
MS4	336.2	0.6%		0.0	0.0%	
Other Permitted Point Sources	31.51	0.1%		21.8	0.0%	
Channel Erosion	40,029.6	69.4%	1.11	35,324.5	65.7%	0.98
Watershed Total	**57,647.8**	100.0%		**53,761.4**	100.0%	
Target Sediment TMDL Load =				**53,761.4**		**t/yr**
10% MOS =				5,376.1		t/yr
Load for Allocation =				**48,385.3**		**t/yr**

The benthic TMDL for Lower Opequon Creek is comprised of three required sediment load components - the waste load allocation (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), and is quantified in Table 7.9.

Table 7.9. Lower Opequon Creek TMDL Sediment Goal (t/yr)

TMDL	WLA	LA	MOS
53,761.4	892.3	47,493.0	5,376.1

The margin of safety (MOS) was explicitly defined as 10% of the calculated TMDL, as with Abrams Creek. The waste load allocation (WLA) was calculated as the sum of all maximum permitted TSS loads, as detailed in Table 7.10. The load allocation (LA) - the allowable sediment load from nonpoint sources - was calculated as the target TMDL load minus the MOS minus the WLA. Since the MOS is excluded from allocation, the target load for modeling purposes in Lower Opequon Creek becomes the TMDL minus the MOS (48,385.3 t/yr). MS4 loads from Abrams Creek that were counted in the Lower Opequon were reduced by applying a ratio (0.55) to account for the different upstream drainage areas in the two watersheds used in calculating watershed sediment delivery ratios, as discussed previously in Section 6.4.3.

Table 7.10. Lower Opequon Creek Sediment WLA Allocations (t/yr)

VPDES ID	Name	Permitted Average Daily Load (kg/day)	Permitted Design Flow (MGD)	Permitted Monthly Ave Conc (mg/L)	WLA (t/yr)
VA0002739	Perry, S. M.[1]		0.10	30	4.15
VA0023116	I-81 Rest Area STP[1]	1.36	0.02	24	0.50
VA0027600	A & K Car Wash[1]		0.01	60	0.41
VA0029653	Shalom et Benedictus Lagoon[1]	0.80	0.01	30	0.29
VA0051373	National Fruit[1]		0.06	30	2.49
VA0065552	Opequon Regional AWT[1]	1386	12.2	30	506.05
VA0075191	Parkins Mill STP[1]	227	2.0		82.91
VA0076384	Abex[1]		0.50	30	20.73
VA0088471	Frederick Co. Landfill[1]	9.08	0.08		3.32
VA0088722	Stonebrook Swim Club[1]	0.45			0.16
VA0089010	Franciscan Center[1]	0.18		30	0.07
VA0090808	APAC Virginia WWTP[1]	0.60	0.01	30	0.22
45 - Single Family General Permit 1000 gpd Units[2]			0.001	30	1.87
VAR040053	City of Winchester[3]				269.2
VAR040032	VDOT - Winchester Urban Area[3]				
WLA Total					**892.3**

[1] The existing TSS load from permitted dischargers is calculated from the average of all monthly reported maximum daily flow and maximum daily concentration.
[2] General Permit Loads are calculated as the number of units (45) multiplied by the maximum daily flow (1000 gpd) and the maximum TSS concentration (30 mg/L).
[3] Existing loads in MS4 areas are calculated as the modeled loads from urban transitional and impervious areas within the City limits.

7.3.2. TMDL Allocation Scenarios

Because of expected future growth in the watershed, TMDL modeling scenarios were run for varying levels of build-out within Frederick County's Urban Designated Areas (UDAs) and Commercial Center (ComCntrs) planning zones within the Opequon Creek watershed, as shown in Table 7.11. Based on growth rates seen in other urbanizing rural areas, the 25% Buildout option was selected as most appropriate. The increase in the other Permitted Point Sources was due to basing future loads for each permitted facility on its permitted design flow and maximum daily average TSS concentration rather than on reported monthly DMR data, as in the existing scenario.

Table 7.11. Lower Opequon Creek Projected Future Sediment Loads (t/yr)

	% Buildout within UDAs and ComCntrs		
Sediment Sources	**25% (t/yr)**	**50% (t/yr)**	**100% (t/yr)**
High Till	8,525	8,360	8,020
Low Till	2,814	2,760	2,648
Pasture	1,844	1,724	1,481
Urban grasses	532	532	531
Orchards	48	47	43
Forest	86	79	65
Transitional	1,658	1,658	1,656
Pervious Urban	326	412	583
Impervious Urban	1,695	2,237	3,322
MS4	398	461	585
Other Permitted Point Sources	623	623	623
Channel Erosion	54,209	68,552	98,045
Watershed Totals	**72,759.5**	**87,444.0**	**117,601.3**

The reductions required to meet the TMDL from existing and future conditions based on the 25% Buildout scenario will need to be made to the target modeling load, as summarized in Table 7.12.

Table 7.12. Summary of Required Reductions for Lower Opequon Creek

	Opequon Creek	**Reductions Required**	
Load Summary	**(t/yr)**	**(t/yr)**	**(% of Existing Load)**
Projected Future Load*	68,784	20,398	40.4%
Existing Load*	50,441	2,056	4.1%
TMDL	53,761		
Target Modeling Load (TMDL-MOS)	48,385		

* Opequon Creek loads reduced by upstream reductions called for in Abrams Creek TMDL.

Since the Abrams Creek watershed is part of the Lower Opequon Creek watershed, reductions in sediment load to the Abrams Creek TMDL allocation will also contribute to the reductions in the Lower Opequon Creek watershed. These reductions are accounted for in Table 7.13 by applying the ratio of the area-based delivery ratios (0.55) to the reductions called for in the Abrams Creek TMDL Alternative 3, and subtracting from the modeled Future25 loads in the Lower Opequon.

Table 7.13. Adjusting Lower Opequon Creek for Abrams TMDL Reductions (t/yr)

Source Category	Future25 Lower Opequon (t/yr)	Abrams Creek TMDL Reductions (t/yr)	Abrams Reductions Applied to Lower Opequon (t/yr)[1]	Future25 Lower Opequon - Abrams Reductions (t/yr)
Agriculture	13,232.0	126.9	70.3	13,161.8
Urban	4,210.9	353.6	195.8	4,015.1
Forestry	86.4	0.0	0.0	86.4
Channel Erosion	54,208.6	3,627.9	3,627.9	50,580.7
MS4	398.4	147.6	81.7	316.7
Point Sources	623.2	0.0	0.0	623.2
Total	**72,759.5**	**4,256.0**	**3,975.7**	**68,783.7**

[1] Abrams Creek TMDL Reductions * Lower Opequon sediment delivery ratio (0.0780) / Abrams Creek sediment delivery ratio (0.1409)

TMDL allocation scenarios were developed by consolidating nonpoint source loads into 3 categories – agriculture, urban, and forestry – and then comparing category loads from the Lower Opequon Creek watershed (minus Abrams Creek reductions) to those of its area-adjusted reference in Table 7.14. “Urban” and MS4 loads were generated as one land use category in the model, but they were separated during the spreadsheet post-processing, since MS4 loads are required to be included in the WLA portion of the TMDL. The comparison in Table 7.14 shows that the annual average sediment loads from forestry and point sources contribute <1% of the total load, so no reductions were required from them.

Table 7.14. Categorized Sediment Loads for Lower Opequon Creek (t/yr)

Source Category	Future25 Lower Opequon - Abrams Reductions (t/yr)	TMDL Target Area Adjusted Upper Opequon (t/yr)
Agriculture	13,161.8	15,075.9
Urban	4,015.1	3,167.2
Forestry	86.4	172.0
Channel Erosion	50,580.7	35,324.5
MS4	316.7	0.0
Point Sources	623.2	21.8
Total	**68,783.7**	**53,761.4**

Three alternative TMDL allocation scenarios were developed around the four remaining source categories, as shown in Table 7.14. Varying levels of sediment reduction in the allocation scenarios were also required from implementation of BMPs in MS4 permitted areas, with equal reductions from the “urban” category. Alternative 1 takes all of the reductions from the major source category - channel erosion - with a smaller fixed load from “agriculture” to account for streambank stabilization needed to complement the reductions required from channel erosion. Alternative 2 takes equal percentage reductions from all four of the remaining source categories. Alternative 3 takes the major reduction from channel erosion, with a smaller percentage reduction taken from the other three. The recommended TMDL allocation scenario is Alternative 3, as it balances the probable greater cost of obtaining reductions from urban areas, with the probability of obtaining greater reductions from the largest source category - "channel erosion".

Table 7.15. TMDL Allocation Scenarios for Lower Opequon Creek

Source Category	Future25 Lower Opequon - Abrams TMDL Reductions	Opequon Creek TMDL Sediment Load Allocations: TMDL Alternative 1 (% reduction)	TMDL Alternative 1 (t/yr)	TMDL Alternative 2 (% reduction)	TMDL Alternative 2 (t/yr)	TMDL Alternative 3 (% reduction)	TMDL Alternative 3 (t/yr)
Agriculture	13,161.8	**10%**	11,845.6	**30.0%**	9,217.8	**15%**	11,187.5
Urban	4,015.1	0%	4,015.1	**30.0%**	2,812.0	**15%**	3,412.9
Forestry	86.4	0%	86.4	0%	86.4	0%	86.4
Channel Erosion	50,580.7	**37.7%**	31,498.4	**30.0%**	35,424.2	**35.1%**	32,806.2
MS4*	316.7	0%	316.7	**30.0%**	221.8	**15%**	269.2
Point Sources	623.2	0%	623.2	0%	623.2	0%	623.2
Total	**68,783.7**		**48,385.3**		**48,385.3**		**48,385.3**

* Percent reductions in loads from MS4 areas were assumed equal to those from all Urban sources.

7.4. Summary

The benthic TMDLs for both Abrams Creek and the Lower Opequon Creek were achieved through sediment reductions from the major source category - "channel erosion", although a small reduction was required from "agriculture" sources for streambank stabilization to accompany the "channel erosion" reductions. Additionally, MS4 loads were reduced to simulate installation of storm water BMPs that are anticipated to accompany compliance with this regulation. "Urban" loads were reduced by the same percentage as existing MS4 loads, as these are essentially the same type of land use. The TMDL to address the benthic impairment in Abrams Creek is 6,327.3 t/yr of sediment. Compared to the existing load, a reduction of 47.8% will be required from projected future loads. The TMDL to address the benthic impairment in Lower Opequon Creek is 53,761.4 t/yr of sediment and will require an overall reduction from projected future loads of 35.1% of the existing load, after accounting for expected reductions from the TMDL for sediment in the upstream Abrams Creek. From the three alternative scenarios explored for each impaired watershed, Alternative 3 was recommended in both cases because it uses the largest reduction from the major source category with smaller reductions from the urban sources that may be more difficult or expensive to control. The major source category in each impaired watershed also generated larger loads than its counterpart from the respective area-adjusted TMDL reference watersheds. The majority of additional sediment generated by future land use changes is likely to be due to increased total and peak runoff from an increasing amount of impervious area that can affect both surface erosion and channel erosion. Much of this increase in runoff and sediment load is expected to be attenuated through compliance with the new MS4 discharge regulations that should accompany future development. The impacts of future development and the MS4 regulations will be documented through DEQ’s continuing biological and ambient water quality monitoring, and should be taken into consideration during development of implementation plans for both Abrams Creek and Lower Opequon Creek.

The Abrams Creek and Lower Opequon Creek watersheds each used Upper Opequon Creek as a TMDL reference watershed. The TMDL to address the benthic impairment in each watershed was developed to meet the existing sediment load from the Upper Opequon watershed, after it was area-adjusted independently to each of the impaired watersheds. The TMDL was developed to take into account all major sediment sources in the watershed from both point and nonpoint sources, and to consider future land use changes. The sediment loads were averaged over a 6-year period to take into account both wet and dry periods in the hydrologic cycle, and the model inputs took into consideration seasonal variations and critical conditions related to sediment loading. An explicit 10% margin of safety was added into the final TMDL load calculation.

CHAPTER 8: BENTHIC TMDL IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the benthic impairments on Abrams Creek and Lower Opequon Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf . With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

8.1. Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement. The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;

3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. Specific goals for BMP implementation will be established as part of the implementation plan development.

8.2. Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. The BMPs required for the implementation of the sediment allocations in the watersheds contribute directly to the sediment reduction goals set as part of the Chesapeake Bay restoration effort. A new tributary strategy is currently being developed for the Shenandoah-Potomac River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. Up-to-date information on tributary strategy development can be found at http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm .

8.3. Reasonable Assurance for Implementation

8.3.1. Follow-Up Monitoring

VADEQ will continue sampling at the established biological monitoring stations (ABR000.78 and OPE029.61) in accordance with its biological monitoring program. VADEQ will continue to use data from these monitoring stations and related ambient monitoring stations to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the general water quality standard.

8.3.2. Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

8.3.3. Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for storm water discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when:…(2) Numeric effluent limitations are infeasible,…".

Parts of the Abrams Creek and Lower Opequon Creek watersheds are covered by Phase II VPDES permits VAR040053 and VAR040032 for the small municipal separate storm sewer systems (MS4s) owned by the City of Winchester and the VDOT-Winchester Urban Area, respectively. Both of these permits were issued on December 9, 2002. The effective dates of coverage are March 12, 2003 and June 24, 2003, respectively. The permits state, under Part II.A., that the "permittee must develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law."

The permit also contains a TMDL clause that states: "If a TMDL is approved for any waterbody into which the small MS4 discharges, the Board will review the TMDL to determine whether the TMDL includes requirements for control of storm water discharges. If discharges from the MS4 are not meeting the TMDL allocations, the Board will notify the permittee of that finding and may require that the Storm Water Management Program required in Part II be modified to implement the TMDL within a timeframe consistent with the TMDL."

For MS4/VPDES general permits, DEQ expects revisions to the permittee's Stormwater Pollution Prevention Plans to specifically address the TMDL pollutants of concern. DEQ anticipates that BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. Any changes to the TMDL resulting from water quality standards changes on Abrams Creek and Opequon Creek would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

Additional information on Virginia's Storm Water Phase II program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.deq.state.va.us/water/bmps.html .

8.3.4. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement Program (CREP) and the Environmental Quality Incentive Program (EQIP), the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

CHAPTER 9: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development process in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In February of 2003, members of the Virginia Tech TMDL group traveled to Frederick County to become acquainted with Abrams Creek watershed. The Virginia Tech TMDL group also traveled to Fredrick and Clarke Counties in March of 2003 to become acquainted with Upper and Lower Opequon watersheds. During those trips, the members of the group spoke with various stakeholders. In addition, personnel from Virginia Tech, the Lord Fairfax Soil and Water Conservation District (SWCD), and the Natural Resource Conservation Service (NRCS) visited some watershed residents and contacted others via telephone, and met with Winchester City officials to acquire their input and collect additional information. The first public meeting for Abrams Creek was held on March 13, 2003, at Shenandoah University in Winchester, VA, to inform the stakeholders about the TMDL study and presented information about both the benthic impairment and a concurrent bacteria impairment. Approximately 45 stakeholders attended this meeting. Copies of the presentation materials and Virginia Cooperative Extension publications discussing the development of the TMDL were available for public distribution at the meeting. The public comment period for information shared at this meeting ended on April 13, 2003.

The first public meeting for the benthic impairment in the Lower Opequon Creek was organized on April 3, 2003, and held at Shenandoah University in Winchester, VA, to inform the stakeholders of the benthic TMDL study on the Lower Opequon, as well as concurrent bacteria TMDL studies on both the Lower and Upper Opequon watersheds. Approximately 45 stakeholders attended this meeting. Copies of the presentation materials and Virginia Cooperative Extension publications discussing the development of the TMDL were available for public distribution at the meeting. The public comment period for information shared at this meeting ended on May 3, 2003. After consulting with DEQ, the decision was made to organize the final public meetings and the TMDL reports around the impairment type – benthic or bacteria – rather than by watershed, since Abrams Creek is tributary to the Lower Opequon. As a result, two final public meetings were held to address the two different types of impairments in the Opequon Creek watershed. The final public meeting to discuss the benthic impairments was public noticed on June 16, 2003 and held on July 1, 2003 at Shenandoah University in Winchester, VA to present the draft TMDL report and solicit comments from stakeholders. Approximately 10 people attended the final meeting. Copies of the presentation materials and

Virginia Cooperative Extension publications discussing the draft TMDL were available for public distribution at the meeting. The public comment period ended on August 1, 2003. A summary of the questions and answers discussed at the meeting will be prepared and made available from the VADEQ Valley Regional Office in Harrisonburg, VA.

CHAPTER 10: REFERENCES

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APPENDIX A. Glossary of Terms

Allocation
That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario
A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels
Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

Best Management Practices (BMP)
Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Calibration
The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

E-911 digital data
Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system
Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform
A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Hydrology
The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Load allocation (LA)
The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)
A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model
Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Nonpoint source
Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Point source
Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution
Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach
Segment of a stream or river.

Runoff
That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system
An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation
The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe
Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)
The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff
Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)
Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)
The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard
Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed
A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

APPENDIX B. Construction of Future Land Use Scenarios

Areas susceptible to land use changes were defined as Frederick County's Urban Development Areas (UDAs) and Commercial Centers (ComCntrs) within the Opequon Creek watershed.

Land uses within the entire Opequon Creek watershed and within just the Opequon Creek UDAs and ComCntrs were summarized by the 3 component drainage areas – Abrams Creek, the Upper Opequon, and the Lower Opequon Remnant (as illustrated previously in Figure 3.1). These summaries are reported in Tables B.1 and B.2, respectively.

Table B.1. Existing Land Use Distribution – Entire Opequon Creek Watershed

Landuse	Abrams Creek		Upper Opequon		Lower Opequon Remnant		Entire Opequon	
Category	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	1,083.49	21.8%	4,200.56	28.1%	4,324.95	26.4%	9,609.00	26.5%
Water	20.62	0.4%	98.05	0.7%	69.60	0.4%	188.27	0.5%
Barren	48.38	1.0%	105.12	0.7%	101.58	0.6%	255.09	0.7%
Commercial	820.20	16.5%	545.62	3.7%	464.28	2.8%	1,830.10	5.0%
Open Urban (vegetated)	494.53	9.9%	351.41	2.4%	224.01	1.4%	1,069.95	2.9%
Orchards	275.78	5.5%	604.99	4.0%	488.13	3.0%	1,368.91	3.8%
LDR	74.34	1.5%	315.14	2.1%	469.62	2.9%	859.11	2.4%
MDR	898.84	18.1%	740.44	5.0%	219.95	1.3%	1,859.22	5.1%
HDR	174.20	3.5%	50.79	0.3%	17.23	0.1%	242.22	0.7%
Cropland	34.16	0.7%	804.40	5.4%	934.13	5.7%	1,772.69	4.9%
Pasture 1 (Improved)	883.18	17.8%	6,139.70	41.1%	8,200.21	50.0%	15,223.10	41.9%
Pasture 2 (Unimproved)	164.79	3.3%	955.87	6.4%	838.19	5.1%	1,958.85	5.4%
Pasture 3	0.00	0.0%	31.00	0.2%	53.35	0.3%	84.35	0.2%
Watershed Total	4,972.53		14,943.10		16,405.24		36,320.88	

Table B.2. Existing Land Use Distribution – Opequon Creek UDAs and ComCntrs

Landuse	Abrams Creek		Upper Opequon		Lower Opequon Remnant		Entire Opequon	
Category	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	764.64	19.3%	1,389.96	27.9%	716.94	20.3%	2,871.54	23.0%
Water	15.84	0.4%	31.41	0.6%	19.62	0.6%	66.87	0.5%
Barren	19.17	0.5%	36.09	0.7%	2.79	0.1%	58.05	0.5%
Commercial	815.49	20.6%	445.68	8.9%	403.47	11.4%	1,664.64	13.3%
Open Urban (vegetated)	485.19	12.3%	328.68	6.6%	194.49	5.5%	1,008.36	8.1%
Orchards	66.33	1.7%	44.10	0.9%	96.48	2.7%	206.91	1.7%
LDR	59.94	1.5%	73.62	1.5%	97.74	2.8%	231.30	1.9%
MDR	895.32	22.6%	617.40	12.4%	169.65	4.8%	1,682.37	13.5%
HDR	173.52	4.4%	51.93	1.0%	15.75	0.4%	241.20	1.9%
Cropland	5.13	0.1%	94.05	1.9%	127.89	3.6%	227.07	1.8%
Pasture 1 (Improved)	522.54	13.2%	1,552.95	31.1%	1,564.11	44.3%	3,639.60	29.2%
Pasture 2 (Unimproved)	130.77	3.3%	315.45	6.3%	123.30	3.5%	569.52	4.6%
Pasture 3	0.00	0.0%	7.65	0.2%	0.00	0.0%	7.65	0.1%
Watershed Total	3,953.88		4,988.97		3,532.23		12,475.08	
Areas to be Reduced	1,489.41		3,404.16		2,628.72		7,522.29	
Areas to be Increased	1,944.27		1,188.63		686.61		3,819.51	

Land use changes within UDAs and ComCntrs were made according to the assumptions stated previously in Section 3.6. Areas from declining land uses were then redistributed to the increasing land uses in proportion to their existing areas within each of the 3 major sub-watersheds. Areas were then recalculated within the UDAs and ComCntrs for the 25%, 50%, and 100% BuildOut scenarios. These area summaries are included in Tables B.3, B.4, and B.5.

Table B.3. Land Use Distribution within UDAs and ComCntrs – 25% BuildOut

Landuse	Abrams Creek		Upper Opequon		Lower Opequon Remnant		Entire Opequon	
Category	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	573.48	14.5%	1,042.47	20.9%	537.71	15.2%	2,153.66	17.3%
Water	15.84	0.4%	31.41	0.6%	19.62	0.6%	66.87	0.5%
Barren	19.17	0.5%	36.09	0.7%	2.79	0.1%	58.05	0.5%
Commercial	970.02	24.5%	759.96	15.2%	751.37	21.3%	2,452.81	19.7%
Open Urban (vegetated)	485.19	12.3%	328.68	6.6%	194.49	5.5%	1,008.36	8.1%
Orchards	49.75	1.3%	33.08	0.7%	72.36	2.0%	155.18	1.2%
LDR	76.23	1.9%	137.86	2.8%	212.71	6.0%	401.84	3.2%
MDR	1,066.58	27.0%	1,054.37	21.1%	352.00	10.0%	2,501.71	20.1%
HDR	203.80	5.2%	87.48	1.8%	27.71	0.8%	343.72	2.8%
Cropland	3.85	0.1%	70.54	1.4%	95.92	2.7%	170.30	1.4%
Pasture 1 (Improved)	391.91	9.9%	1,164.71	23.3%	1,173.08	33.2%	2,729.70	21.9%
Pasture 2 (Unimproved)	98.08	2.5%	236.59	4.7%	92.48	2.6%	427.14	3.4%
Pasture 3	0.00	0.0%	5.74	0.1%	0.00	0.0%	5.74	0.0%
Watershed Total	3,953.88		4,988.97		3,532.23		12,475.08	

Table B.4. Land Use Distribution within UDAs and ComCntrs – 50% BuildOut

Landuse	Abrams Creek		Upper Opequon		Lower Opequon Remnant		Entire Opequon	
Category	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	382.32	9.7%	694.98	13.9%	358.47	10.1%	1,435.77	11.5%
Water	15.84	0.4%	31.41	0.6%	19.62	0.6%	66.87	0.5%
Barren	19.17	0.5%	36.09	0.7%	2.79	0.1%	58.05	0.5%
Commercial	1,124.55	28.4%	1,074.23	21.5%	1,099.28	31.1%	3,240.97	26.0%
Open Urban (vegetated)	485.19	12.3%	328.68	6.6%	194.49	5.5%	1,008.36	8.1%
Orchards	33.17	0.8%	22.05	0.4%	48.24	1.4%	103.46	0.8%
LDR	92.52	2.3%	202.10	4.1%	327.69	9.3%	572.38	4.6%
MDR	1,237.84	31.3%	1,491.33	29.9%	534.34	15.1%	3,321.06	26.6%
HDR	234.08	5.9%	123.04	2.5%	39.66	1.1%	446.25	3.6%
Cropland	2.57	0.1%	47.03	0.9%	63.95	1.8%	113.54	0.9%
Pasture 1 (Improved)	261.27	6.6%	776.48	15.6%	782.06	22.1%	1,819.80	14.6%
Pasture 2 (Unimproved)	65.39	1.7%	157.73	3.2%	61.65	1.7%	284.76	2.3%
Pasture 3	0.00	0.0%	3.83	0.1%	0.00	0.0%	3.83	0.0%
Watershed Total	3,953.88		4,988.97		3,532.23		12,475.08	

Table B.5. Land Use Distribution within UDAs and ComCntrs – 100% BuildOut

Landuse	Abrams Creek		Upper Opequon		Lower Opequon Remnant		Entire Opequon	
Category	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Water	15.84	0.4%	31.41	0.6%	19.62	0.6%	66.87	0.5%
Barren	19.17	0.5%	36.09	0.7%	2.79	0.1%	58.05	0.5%
Commercial	1,433.60	36.3%	1,702.78	34.1%	1,795.09	50.8%	4,817.31	38.6%
Open Urban (vegetated)	485.19	12.3%	328.68	6.6%	194.49	5.5%	1,008.36	8.1%
Orchards	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
LDR	125.10	3.2%	330.59	6.6%	557.63	15.8%	913.46	7.3%
MDR	1,580.35	40.0%	2,365.27	47.4%	899.04	25.5%	4,959.74	39.8%
HDR	294.63	7.5%	194.15	3.9%	63.57	1.8%	651.30	5.2%
Cropland	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Pasture 1 (Improved)	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Pasture 2 (Unimproved)	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Pasture 3	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Watershed Total	3,953.88		4,988.97		3,532.23		12,475.08	

Future land use distributions were calculated by first subtracting areas in Table B.2 from Table B.1, and then adding in the redistributed land use areas from Tables B.3, B.4, and B.5, respectively, to generate the Future25, Future50, and Future100 projected land use distributions in Tables B.6, B.7, and B.8.

Table B.6. Future25 Land Use Distribution – Entire Opequon Creek Watershed

Landuse Category	Abrams Creek (ha)	(%)	Upper Opequon (ha)	(%)	Lower Opequon Remnant (ha)	(%)	Entire Opequon (ha)	(%)
Forest	318.85	6.4%	2,810.60	18.8%	3,608.01	22.0%	6,737.46	18.5%
Water	20.62	0.4%	98.05	0.7%	69.60	0.4%	188.27	0.5%
Barren	48.38	1.0%	105.12	0.7%	101.58	0.6%	255.09	0.7%
Commercial	1,438.31	28.9%	1,802.73	12.1%	1,855.90	11.3%	5,096.94	14.0%
Open Urban (vegetated)	494.53	9.9%	351.41	2.4%	224.01	1.4%	1,069.95	2.9%
Orchards	209.45	4.2%	560.89	3.8%	391.65	2.4%	1,162.00	3.2%
LDR	139.50	2.8%	572.11	3.8%	929.51	5.7%	1,641.12	4.5%
MDR	1,583.87	31.9%	2,488.31	16.7%	949.34	5.8%	5,021.51	13.8%
HDR	295.31	5.9%	193.01	1.3%	65.05	0.4%	553.38	1.5%
Cropland	29.03	0.6%	710.35	4.8%	806.24	4.9%	1,545.62	4.3%
Pasture 1 (Improved)	360.64	7.3%	4,586.75	30.7%	6,636.10	40.5%	11,583.50	31.9%
Pasture 2 (Unimproved)	34.02	0.7%	640.42	4.3%	714.89	4.4%	1,389.33	3.8%
Pasture 3	0.00	0.0%	23.35	0.2%	53.35	0.3%	76.70	0.2%
Watershed Total	4,972.53		14,943.10		16,405.24		36,320.88	

Table B.7. Future50 Land Use Distribution – Entire Opequon Creek Watershed

Landuse Category	Abrams Creek (ha)	(%)	Upper Opequon (ha)	(%)	Lower Opequon Remnant (ha)	(%)	Entire Opequon (ha)	(%)
Forest	701.17	14.1%	3,505.58	23.5%	3,966.48	24.2%	8,173.23	22.5%
Water	20.62	0.4%	98.05	0.7%	69.60	0.4%	188.27	0.5%
Barren	48.38	1.0%	105.12	0.7%	101.58	0.6%	255.09	0.7%
Commercial	1,129.26	22.7%	1,174.17	7.9%	1,160.09	7.1%	3,463.52	9.5%
Open Urban (vegetated)	494.53	9.9%	351.41	2.4%	224.01	1.4%	1,069.95	2.9%
Orchards	242.62	4.9%	582.94	3.9%	439.89	2.7%	1,265.45	3.5%
LDR	106.92	2.2%	443.62	3.0%	699.57	4.3%	1,250.11	3.4%
MDR	1,241.35	25.0%	1,614.37	10.8%	584.64	3.6%	3,440.37	9.5%
HDR	234.75	4.7%	121.90	0.8%	41.14	0.3%	397.80	1.1%
Cropland	31.60	0.6%	757.37	5.1%	870.18	5.3%	1,659.15	4.6%
Pasture 1 (Improved)	621.91	12.5%	5,363.23	35.9%	7,418.16	45.2%	13,403.30	36.9%
Pasture 2 (Unimproved)	99.41	2.0%	798.15	5.3%	776.54	4.7%	1,674.09	4.6%
Pasture 3	0.00	0.0%	27.18	0.2%	53.35	0.3%	80.53	0.2%
Watershed Total	4,972.53		14,943.10		16,405.24		36,320.88	

Table B.8. Future100 Land Use Distribution – Entire Opequon Creek Watershed

Landuse Category	Abrams Creek (ha)	(%)	Upper Opequon (ha)	(%)	Lower Opequon Remnant (ha)	(%)	Entire Opequon (ha)	(%)
Forest	318.85	6.4%	2,810.60	18.8%	3,608.01	22.0%	6,737.46	18.5%
Water	20.62	0.4%	98.05	0.7%	69.60	0.4%	188.27	0.5%
Barren	48.38	1.0%	105.12	0.7%	101.58	0.6%	255.09	0.7%
Commercial	1,438.31	28.9%	1,802.73	12.1%	1,855.90	11.3%	5,096.94	14.0%
Open Urban (vegetated)	494.53	9.9%	351.41	2.4%	224.01	1.4%	1,069.95	2.9%
Orchards	209.45	4.2%	560.89	3.8%	391.65	2.4%	1,162.00	3.2%
LDR	139.50	2.8%	572.11	3.8%	929.51	5.7%	1,641.12	4.5%
MDR	1,583.87	31.9%	2,488.31	16.7%	949.34	5.8%	5,021.51	13.8%
HDR	295.31	5.9%	193.01	1.3%	65.05	0.4%	553.38	1.5%
Cropland	29.03	0.6%	710.35	4.8%	806.24	4.9%	1,545.62	4.3%
Pasture 1 (Improved)	360.64	7.3%	4,586.75	30.7%	6,636.10	40.5%	11,583.50	31.9%
Pasture 2 (Unimproved)	34.02	0.7%	640.42	4.3%	714.89	4.4%	1,389.33	3.8%
Pasture 3	0.00	0.0%	23.35	0.2%	53.35	0.3%	76.70	0.2%
Watershed Total	4,972.53		14,943.10		16,405.24		36,320.88	

The graphs in Figure B.1 illustrate the land use specific changes within the 3 sub-watersheds and the entire watershed for the 100% BuildOut scenario.

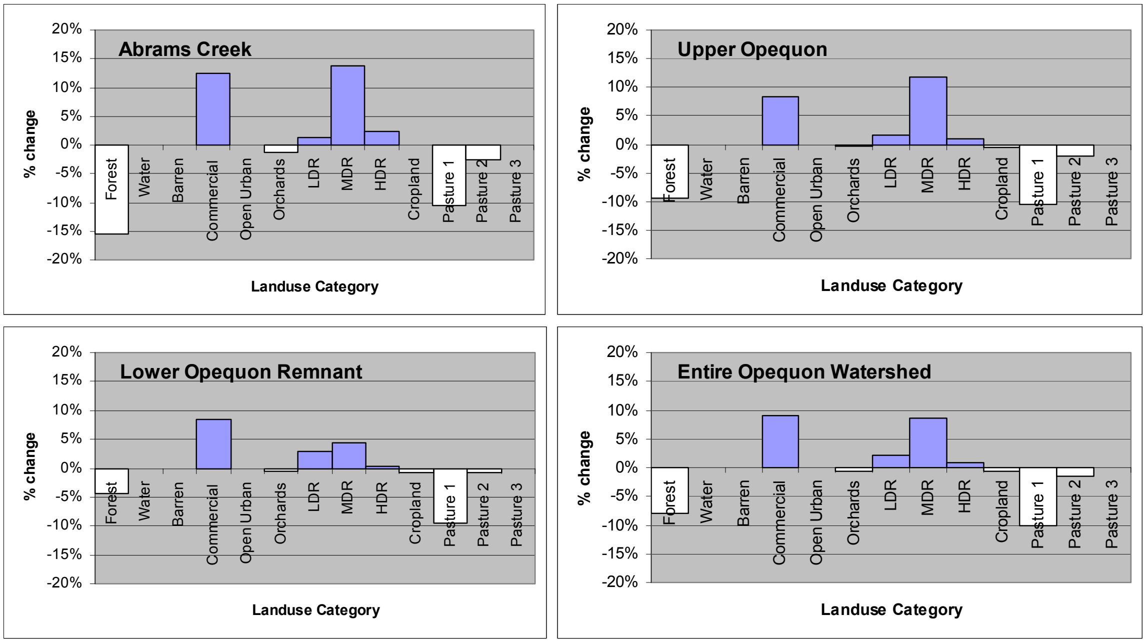

Figure B.1. Changes between Existing and Future100 Land Use Areas

The pie charts in Figure B.2 illustrate the shift in major land use categories for the entire Opequon Creek watershed for the existing and the 3 projected future scenarios.

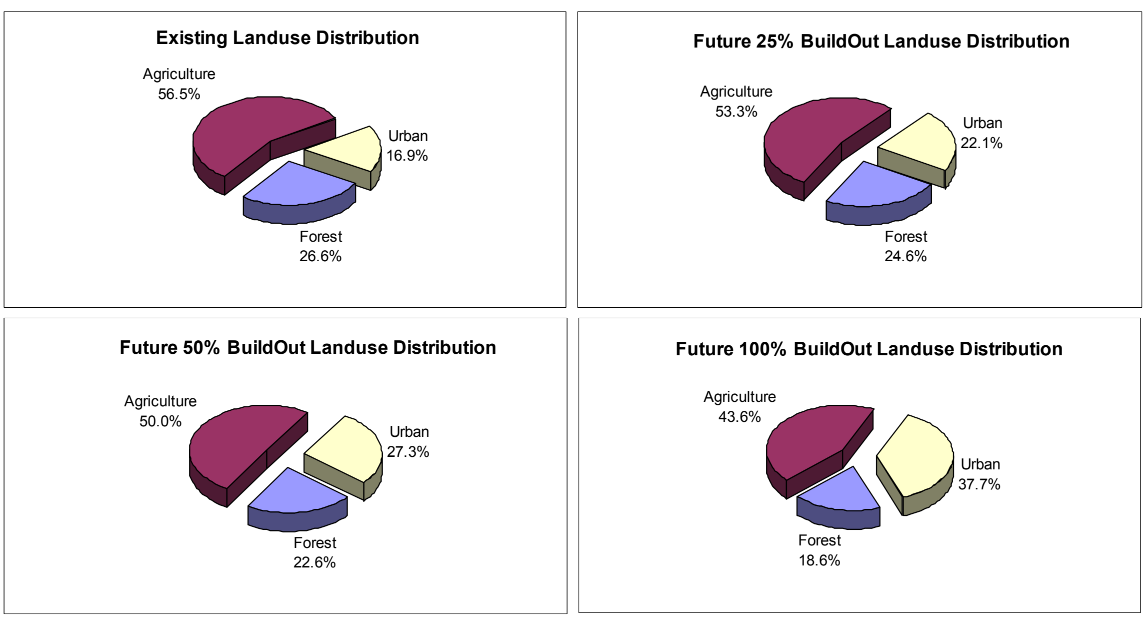

Figure B.2. Major Land Use Category Distributions

APPENDIX C. SUB-WATERSHED PARAMETERIZATION AND SEDIMENT LOADING

Table C.1. Sub-watershed Land Use Distributions - Existing and Future Scenarios

ID#	ANCODE	Watershed Description	hit	lot	pa1	pa2	pa3	urbg	orch	for	tran	L-pur	M-pur	H-pur	Com-pu	L-imp	M-imp	H-imp	Com-imp	Water	Land_ha
	Existing Scenario																				
500	ABR	All of Abrams Creek watershed	19.37	14.79	883.18	164.79	0.00	494.53	275.78	1083.49	48.38	65.42	629.19	60.97	172.24	8.92	269.65	113.23	647.96	20.62	4,951.9
715	OPE88	Upper Opequon Creek watershed	455.55	349.09	6,139.70	955.87	31.00	351.41	604.99	4,200.56	105.12	267.87	481.29	15.24	81.84	47.27	259.15	35.55	463.78	98.05	14,845.3
900	LOW	Lower Opequon Creek Remnant	516.34	394.23	7,681.76	743.15	46.95	45.00	438.24	3,788.66	98.80	356.84	104.13	0.00	27.25	62.97	56.07	0.00	154.40	65.16	14,514.8
910	RED	Redbud Run watershed	13.36	10.20	518.46	95.04	6.40	179.01	49.89	536.29	2.78	42.34	38.84	5.17	42.39	7.47	20.91	12.06	240.24	4.44	1,820.8
5001	ABR1	Lower Abrams Creek	0.00	0.00	185.26	79.61	0.00	104.52	0.00	322.89	4.06	11.72	191.84	9.24	31.00	1.60	82.22	17.17	116.63	5.12	1,157.8
5002	ABR2	Eastern Winchester	0.00	0.00	57.49	24.61	0.00	118.67	0.00	146.13	4.59	1.72	163.18	5.93	12.93	0.23	69.94	11.01	48.63	0.45	665.0
5003	ABR3	Lower Town Run	0.00	0.00	6.47	0.00	0.00	85.41	0.00	40.93	0.00	0.07	106.14	2.08	40.09	0.01	45.49	3.86	150.81	1.20	481.4
5004	ABR4	Upper Town Run	0.00	0.00	190.23	0.98	0.00	23.25	118.97	145.38	0.00	9.27	30.81	33.87	15.19	1.26	13.21	62.90	57.13	3.01	702.4
5005	ABR5	Southern Winchester	2.82	2.15	73.89	8.13	0.00	130.63	5.49	128.07	11.21	9.40	109.77	8.06	63.97	1.28	47.04	14.97	240.64	2.11	857.5
5006	ABR6	Upper Abrams Creek	16.56	12.64	369.84	51.47	0.00	32.06	151.32	300.09	28.52	33.24	27.44	1.79	9.07	4.53	11.76	3.33	34.12	8.73	1,087.8
7151	OPEadj	Upper Opequon adjusted to Abrams Creek	151.96	116.45	2,048.01	318.85	10.34	117.22	201.81	1,401.17	35.07	89.35	160.54	5.08	27.30	15.77	86.45	11.86	154.70	39.74	4,951.9
7153	UPPadj	Upper Opequon adjusted to Lower Opequon	1,108.80	849.68	14,943.78	2,326.56	75.46	855.31	1,472.53	10,224.00	255.86	651.98	1,171.43	37.09	199.20	115.05	630.77	86.54	1,128.82	98.0	36,132.9
7154	OPEQ	Entire (Lower) Opequon Creek watershed	1,004.63	768.31	15,223.10	1,958.85	84.35	1,069.95	1,368.91	9,609.00	255.09	732.47	1,253.44	81.38	323.73	126.64	605.79	160.85	1,506.38	188.3	36,132.9
8000	LOWx	Cumulative drainage area to Lower Opequon Creek	1,004.63	768.31	15,223.10	1,958.85	84.35	1,069.95	1,368.91	9,609.00	255.09	732.47	1,253.44	81.38	323.73	126.64	605.79	160.85	1,506.38	188.3	36,132.9
8001	ABR1x	Cumulative drainage area to Lower Abrams Creek	19.37	14.79	883.18	164.79	0.00	494.53	275.78	1,083.49	48.38	65.42	629.19	60.97	172.24	8.92	269.65	113.23	647.96	20.6	4,951.9
8002	ABR2x	Cumulative drainage area to Eastern Winchester	19.37	14.79	697.92	85.18	0.00	390.01	275.78	760.61	44.32	53.70	437.35	51.73	141.24	7.32	187.43	96.06	531.33	15.5	3,794.1
8003	ABR3x	Cumulative drainage area to Lower Town Run	0.00	0.00	196.70	0.98	0.00	108.66	118.97	186.31	0.00	9.34	136.95	35.95	55.28	1.27	58.69	66.76	207.94	4.2	1,183.8
8005	ABR5x	Cumulative drainage area to Southern Winchester	19.37	14.79	443.74	59.60	0.00	162.69	156.82	428.16	39.73	42.64	137.21	9.85	73.04	5.82	58.81	18.29	274.76	10.8	1,945.3
	Future100 Scenario																				
9000	ABRf	All of Abrams Creek watershed	16.46	12.57	360.64	34.02	0.00	494.53	209.45	318.85	48.38	122.76	1108.71	103.36	302.05	16.74	475.16	191.95	1136.27	48.5	4,951.9
9001	OPE88f	Upper Opequon Creek watershed	455.55	349.09	4,586.75	640.42	23.35	351.41	560.89	2,810.60	105.12	486.29	1617.40	57.90	270.41	85.82	870.91	135.11	1532.32	137.8	14,939.4
9002	LOWf	Lower Opequon Creek Remnant	445.65	340.26	6,216.54	633.83	46.95	45.00	351.62	3,160.62	98.80	706.28	449.45	0.00	108.92	124.64	242.01	0.00	617.20	286.3	13,587.8
9003	REDf	Redbud Run watershed	11.53	8.80	419.57	81.06	6.40	179.01	40.03	447.39	2.78	83.81	167.62	19.52	169.47	14.79	90.26	45.54	960.31	376.5	2,747.9
9004	ABR1f	Lower Abrams Creek	0.00	0.00	75.65	16.44	0.00	104.52	0.00	95.02	4.06	21.99	338.04	15.67	54.37	3.00	144.88	29.10	204.53	208.9	1,107.3
9005	ABR2f	Eastern Winchester	0.00	0.00	23.48	5.08	0.00	118.67	0.00	43.00	4.59	3.23	287.55	10.05	22.67	0.44	123.24	18.66	85.27	36.1	745.9
9006	ABR3f	Lower Town Run	0.00	0.00	2.64	0.00	0.00	85.41	0.00	12.05	0.00	0.12	187.03	3.53	70.30	0.02	80.15	6.55	264.47	19.7	712.3
9007	ABR4f	Upper Town Run	0.00	0.00	77.68	0.20	0.00	23.25	90.35	42.78	0.00	17.40	54.30	57.42	26.63	2.37	23.27	106.63	100.18	15.0	622.5
9008	ABR5f	Southern Winchester	2.39	1.83	30.17	1.68	0.00	130.63	4.17	37.69	11.21	17.64	193.43	13.66	112.17	2.41	82.90	25.37	421.98	59.3	1,089.3
9009	ABR6f	Upper Abrams Creek	14.07	10.74	151.02	10.63	0.00	32.06	114.93	88.31	28.52	62.37	48.36	3.04	15.91	8.51	20.72	5.64	59.84	186.2	674.7
9010	OPEadjf	Upper Opequon adjusted to Abrams Creek	151.00	115.71	1,520.36	212.28	7.74	116.48	185.92	931.62	34.84	161.19	536.12	19.19	89.63	28.45	288.68	44.78	507.91	424.1	4,951.9
9011	UPPadjf	Upper Opequon adjusted to Lower Opequon	1,104.69	846.53	11,122.56	1,552.98	56.63	852.14	1,360.13	6,815.52	254.91	1,179.22	3,922.08	140.41	655.72	208.10	2,111.89	327.63	3,715.76	662.9	36,226.9
9012	OPEQf	Entire (Lower) Opequon Creek watershed	929.20	710.72	11,583.50	1,389.33	76.70	1,069.95	1,162.00	6,737.46	255.09	1,399.14	3,343.18	180.78	850.84	241.98	1,678.34	372.60	4,246.10	585.4	36,226.9
9013	LOWxf	Cumulative drainage area to Lower Opequon Creek	929.20	710.72	11,583.50	1,389.33	76.70	1,069.95	1,162.00	6,737.46	255.09	1,399.14	3,343.18	180.78	850.84	241.98	1,678.34	372.60	4,246.10	245.0	36,226.9
9014	ABR1xf	Cumulative drainage area to Lower Abrams Creek	16.46	12.57	360.64	34.02	0.00	494.53	209.45	318.85	48.38	122.76	1,108.71	103.36	302.05	16.74	475.16	191.95	1,136.27	55.8	4,951.9
9015	ABR2xf	Cumulative drainage area to Eastern Winchester	16.46	12.57	284.99	17.59	0.00	390.01	209.45	223.83	44.32	100.77	770.67	87.69	247.68	13.74	330.29	162.85	931.74	34.8	3,844.6
9016	ABR3xf	Cumulative drainage area to Lower Town Run	0.00	0.00	80.32	0.20	0.00	108.66	90.35	54.83	0.00	17.52	241.33	60.94	96.93	2.39	103.43	113.18	364.65	74.3	1,334.7
9017	ABR5xf	Cumulative drainage area to Southern Winchester	16.46	12.57	181.20	12.30	0.00	162.69	119.10	126.00	39.73	80.02	241.79	16.70	128.08	10.91	103.62	31.01	481.82	245.5	1,764.0
	Future50 Scenario																				
9018	ABRx50	All of Abrams Creek watershed	17.92	13.68	621.91	99.41	0.00	494.53	242.62	701.17	48.38	94.09	868.95	82.16	237.14	12.83	372.41	152.59	892.11	610.4	4,951.9
9019	OPE88x50	Upper Opequon Creek watershed	455.55	349.09	5,363.23	798.15	27.18	351.41	582.94	3,505.58	105.12	377.08	1049.34	36.57	176.13	66.54	565.03	85.33	998.05	1,087.0	14,892.3
9020	LOWx50	Lower Opequon Creek Remnant	481.00	367.24	6,949.15	688.49	46.95	45.00	394.93	3,474.64	98.80	531.56	276.79	0.00	68.08	93.80	149.04	0.00	385.80	1,248.3	14,051.3
9021	REDx50	Redbud Run watershed	12.44	9.50	469.01	88.05	6.40	179.01	44.96	491.84	2.78	63.07	103.23	12.34	105.93	11.13	55.58	28.80	600.28	830.4	2,284.4
9022	ABR1x50	Lower Abrams Creek	0.00	0.00	130.46	48.02	0.00	104.52	0.00	208.95	4.06	16.86	264.94	12.46	42.69	2.30	113.55	23.14	160.58	300.8	1,132.5
9023	ABR2x50	Eastern Winchester	0.00	0.00	40.48	14.84	0.00	118.67	0.00	94.57	4.59	2.48	225.37	7.99	17.80	0.34	96.59	14.83	66.95	90.6	705.5
9024	ABR3x50	Lower Town Run	0.00	0.00	4.56	0.00	0.00	85.41	0.00	26.49	0.00	0.10	146.58	2.80	55.20	0.01	62.82	5.21	207.64	109.1	596.8
9025	ABR4x50	Upper Town Run	0.00	0.00	133.95	0.59	0.00	23.25	104.66	94.08	0.00	13.33	42.56	45.64	20.91	1.82	18.24	84.77	78.65	319.9	662.4
9026	ABR5x50	Southern Winchester	2.60	1.99	52.03	4.90	0.00	130.63	4.83	82.88	11.21	13.52	151.60	10.86	88.07	1.84	64.97	20.17	331.31	855.9	973.4
9027	ABR6x50	Upper Abrams Creek	15.31	11.69	260.43	31.05	0.00	32.06	133.13	194.20	28.52	47.81	37.90	2.41	12.49	6.52	16.24	4.48	46.98	1,697.3	881.2
9028	OPEadjx50	Upper Opequon adjusted to Abrams Creek	151.48	116.08	1,783.35	265.40	9.04	116.85	193.84	1,165.66	34.95	125.38	348.92	12.16	58.56	22.13	187.88	28.37	331.87	2,335.2	4,951.9
9029	UPPadjx50	Upper Opequon adjusted to Lower Opequon	1,106.74	848.10	13,029.59	1,939.05	66.02	853.72	1,416.22	8,516.57	255.38	916.09	2,549.30	88.85	427.89	161.66	1,372.70	207.31	2,424.69	2,078.7	36,179.9
9030	OPEQx50	Entire (Lower) Opequon Creek watershed	966.91	739.52	13,403.30	1,674.09	80.53	1,069.95	1,265.45	8,173.23	255.09	1,065.80	2,298.31	131.08	587.28	184.31	1,142.06	266.72	2,876.24	1,131.3	36,179.9
9031	LOWxx50	Cumulative drainage area to Lower Opequon Creek	966.91	739.52	13,403.30	1,674.09	80.53	1,069.95	1,265.45	8,173.23	255.09	1,065.80	2,298.31	131.08	587.28	184.31	1,142.06	266.72	2,876.24	391.4	36,179.9
9032	ABR1xx50	Cumulative drainage area to Lower Abrams Creek	17.92	13.68	621.91	99.41	0.00	494.53	242.62	701.17	48.38	94.09	868.95	82.16	237.14	12.83	372.41	152.59	892.11	199.7	4,951.9
9033	ABR2xx50	Cumulative drainage area to Eastern Winchester	17.92	13.68	491.46	51.38	0.00	390.01	242.62	492.22	44.32	77.24	604.01	69.71	194.46	10.53	258.86	129.45	731.53	429.0	3,819.4
9034	ABR3xx50	Cumulative drainage area to Lower Town Run	0.00	0.00	138.51	0.59	0.00	108.66	104.66	120.57	0.00	13.43	189.14	48.45	76.10	1.83	81.06	89.97	286.29	1,175.8	1,259.3
9035	ABR5xx50	Cumulative drainage area to Southern Winchester	17.92	13.68	312.47	35.95	0.00	162.69	137.96	277.08	39.73	61.33	189.50	13.27	100.56	8.36	81.22	24.65	378.29	2,553.2	1,854.7
	Future25 Scenario																				
9036	ABRx25	All of Abrams Creek watershed	18.64	14.24	752.55	132.10	0.00	494.53	259.20	892.33	48.38	79.76	749.07	71.57	204.69	10.88	321.03	132.91	770.04	4,032.6	4,951.9
9037	OPE88x25	Upper Opequon Creek watershed	455.55	349.09	5,751.46	877.01	29.09	351.41	593.97	3,853.07	105.12	322.47	765.31	25.90	128.98	56.91	412.09	60.44	730.91	4,414.0	14,868.8
9038	LOWx25	Lower Opequon Creek Remnant	498.67	380.74	7,315.45	715.82	46.95	45.00	416.59	3,631.65	98.80	444.20	190.46	0.00	47.66	78.39	102.56	0.00	270.10	3,210.0	14,283.0
9039	REDx25	Redbud Run watershed	12.90	9.85	493.74	91.54	6.40	179.01	47.42	514.07	2.78	52.71	71.03	8.76	74.16	9.30	38.25	20.43	420.26	1,522.7	2,052.6
9040	ABR1x25	Lower Abrams Creek	0.00	0.00	157.86	63.82	0.00	104.52	0.00	265.92	4.06	14.29	228.39	10.85	36.84	1.95	97.88	20.15	138.61	591.2	1,145.1
9041	ABR2x25	Eastern Winchester	0.00	0.00	48.99	19.72	0.00	118.67	0.00	120.35	4.59	2.10	194.27	6.96	15.36	0.29	83.26	12.92	57.79	628.7	685.3
9042	ABR3x25	Lower Town Run	0.00	0.00	5.51	0.00	0.00	85.41	0.00	33.71	0.00	0.08	126.36	2.44	47.64	0.01	54.15	4.54	179.23	1,604.8	539.1
9043	ABR4x25	Upper Town Run	0.00	0.00	162.09	0.78	0.00	23.25	111.81	119.73	0.00	11.30	36.69	39.76	18.05	1.54	15.72	73.83	67.89	3,729.0	682.4
9044	ABR5x25	Southern Winchester	2.71	2.07	62.96	6.51	0.00	130.63	5.16	105.48	11.21	11.46	130.69	9.46	76.02	1.56	56.01	17.57	285.97	6,585.8	915.5
9045	ABR6x25	Upper Abrams Creek	15.93	12.17	315.14	41.26	0.00	32.06	142.22	247.14	28.52	40.52	32.67	2.10	10.78	5.53	14.00	3.90	40.55	8,446.5	984.5
9046	OPEadjx25	Upper Opequon adjusted to Abrams Creek	151.72	116.26	1,915.47	292.08	9.69	117.03	197.82	1,283.23	35.01	107.40	254.88	8.63	42.96	18.95	137.24	20.13	243.42	7,624.0	4,951.9
9047	UPPadjx25	Upper Opequon adjusted to Lower Opequon	1,107.77	848.89	13,985.78	2,132.62	70.74	854.51	1,444.35	9,369.48	255.62	784.16	1,861.01	62.99	313.65	138.38	1,002.08	146.98	1,777.36	4,732.7	36,156.4
9048	OPEQx25	Entire (Lower) Opequon Creek watershed	985.77	753.91	14,313.20	1,816.47	82.44	1,069.95	1,317.18	8,891.12	255.09	899.14	1,775.87	106.23	455.51	155.47	873.92	213.78	2,191.31	2,113.9	36,156.4
9049	LOWxx25	Cumulative drainage area to Lower Opequon Creek	985.77	753.91	14,313.20	1,816.47	82.44	1,069.95	1,317.18	8,891.12	255.09	899.14	1,775.87	106.23	455.51	155.47	873.92	213.78	2,191.31	1,219.9	36,156.4
9050	ABR1xx25	Cumulative drainage area to Lower Abrams Creek	18.64	14.24	752.55	132.10	0.00	494.53	259.20	892.33	48.38	79.76	749.07	71.57	204.69	10.88	321.03	132.91	770.04	2,233.5	4,951.9
9051	ABR2xx25	Cumulative drainage area to Eastern Winchester	18.64	14.24	594.69	68.28	0.00	390.01	259.20	626.41	44.32	65.47	520.68	60.72	167.85	8.93	223.15	112.76	631.43	5,333.8	3,806.8
9052	ABR3xx25	Cumulative drainage area to Lower Town Run	0.00	0.00	167.60	0.78	0.00	108.66	111.81	153.44	0.00	11.38	163.04	42.20	65.69	1.55	69.88	78.37	247.12	10,314.8	1,221.5
9053	ABR5xx25	Cumulative drainage area to Southern Winchester	18.64	14.24	378.10	47.77	0.00	162.69	147.39	352.62	39.73	51.99	163.36	11.56	86.80	7.09	70.01	21.47	326.52	15,032.3	1,900.0

Table C.2. Average Slope (%) by Land Use and Sub-watershed

ID#	ANCODE	Watershed Description	Hi-Till	Lo-Till	Pasture 1	Pasture 2	Pasture 3	Open Urban (vegetated)	Orchards	Forest	Transitional	LDR	MDR	HDR	Commercial
500	ABR	All of Abrams Creek watershed	7.791	7.791	8.262	7.153	0.000	6.778	8.817	8.804	9.793	7.804	6.870	6.908	6.847
715	OPE88	Upper Opequon Creek watershed	4.627	4.627	6.200	5.885	4.307	5.838	6.301	9.581	9.587	7.054	4.937	3.391	5.844
900	LOW	Lower Opequon Creek Remnant	3.476	3.476	4.591	4.486	4.329	2.910	5.503	6.783	4.626	6.168	4.341	0.000	3.781
910	RED	Redbud Run watershed	6.793	6.793	8.597	9.424	6.832	7.588	12.634	9.743	7.426	10.335	7.065	6.931	7.098
5001	ABR1	Lower Abrams Creek	0.000	0.000	8.747	6.875	0.000	5.787	0.000	8.796	9.801	10.782	7.056	8.350	6.004
5002	ABR2	Eastern Winchester	0.000	0.000	7.405	6.756	0.000	7.365	0.000	9.544	6.827	8.052	6.474	6.739	7.096
5003	ABR3	Lower Town Run	0.000	0.000	11.934	0.000	0.000	6.692	0.000	10.119	0.000	0.000	6.399	4.972	6.907
5004	ABR4	Upper Town Run	0.000	0.000	9.056	5.328	0.000	7.317	9.247	8.642	0.000	5.970	8.172	6.871	8.636
5005	ABR5	Southern Winchester	8.480	8.480	7.790	6.530	0.000	6.883	9.282	7.266	5.438	6.830	7.289	6.238	6.646
5006	ABR6	Upper Abrams Creek	7.674	7.674	7.773	7.906	0.000	7.238	8.461	9.008	11.981	7.545	6.613	5.987	7.537
7151	OPEadj	Upper Opequon adjusted to Abrams Creek	4.627	4.627	6.200	5.885	4.307	5.838	6.301	9.581	9.587	7.054	4.937	3.391	5.844
7153	UPPadj	Upper Opequon adjusted to Lower Opequon	4.627	4.627	6.200	5.885	4.307	5.838	6.301	9.581	9.587	7.054	4.937	3.391	5.844
7154	OPEQ	Entire (Lower) Opequon Creek watershed	4.126	4.126	5.593	5.629	4.514	6.429	6.788	8.396	7.680	6.874	5.884	6.158	6.287

Table C.3. Average Soil Erodibility (K-factor) by Land Use and Sub-watershed

ID#	ANCODE	Watershed Description	Hi-Till	Lo-Till	Pasture 1	Pasture 2	Pasture 3	Open Urban (vegetated)	Orchards	Forest	Transitional	LDR	MDR	HDR	Commercial
500	ABR	All of Abrams Creek watershed	0.320	0.320	0.309	0.255	0.000	0.297	0.322	0.285	0.200	0.312	0.288	0.303	0.311
715	OPE88	Upper Opequon Creek watershed	0.313	0.313	0.304	0.287	0.291	0.331	0.330	0.271	0.224	0.297	0.334	0.364	0.328
900	LOW	Lower Opequon Creek Remnant	0.332	0.332	0.300	0.277	0.316	0.356	0.336	0.267	0.153	0.304	0.324	0.000	0.351
910	RED	Redbud Run watershed	0.325	0.325	0.321	0.279	0.248	0.336	0.318	0.306	0.259	0.311	0.335	0.319	0.338
5001	ABR1	Lower Abrams Creek	0.000	0.000	0.255	0.194	0.000	0.262	0.000	0.239	0.221	0.229	0.258	0.254	0.272
5002	ABR2	Eastern Winchester	0.000	0.000	0.270	0.273	0.000	0.273	0.000	0.241	0.224	0.196	0.269	0.248	0.285
5003	ABR3	Lower Town Run	0.000	0.000	0.320	0.000	0.000	0.320	0.000	0.320	0.000	0.000	0.320	0.320	0.320
5004	ABR4	Upper Town Run	0.000	0.000	0.320	0.320	0.000	0.319	0.320	0.319	0.000	0.320	0.320	0.319	0.322
5005	ABR5	Southern Winchester	0.320	0.320	0.328	0.326	0.000	0.320	0.320	0.322	0.320	0.325	0.320	0.320	0.324
5006	ABR6	Upper Abrams Creek	0.320	0.320	0.332	0.327	0.000	0.335	0.324	0.320	0.146	0.342	0.327	0.333	0.334
7151	OPEadj	Upper Opequon adjusted to Abrams Creek	0.313	0.313	0.304	0.287	0.291	0.331	0.330	0.271	0.224	0.297	0.334	0.364	0.328
7153	UPPadj	Upper Opequon adjusted to Lower Opequon	0.313	0.313	0.304	0.287	0.291	0.331	0.330	0.271	0.224	0.297	0.334	0.364	0.328
7154	OPEQ	Entire (Lower) Opequon Creek watershed	0.323	0.323	0.303	0.279	0.301	0.317	0.330	0.273	0.192	0.303	0.311	0.317	0.324

Table C.4. Hydrologic Soil Group (HSG) % Distribution by Sub-watershed

ID#	ANCODE	Watershed Description	Area (Sq.km.)	HSG=A	HSG=B	HSG=C	HSG=D
500	ABR	All of Abrams Creek watershed	49.519	0.1	3.5	88.2	8.2
715	OPE88	Upper Opequon Creek watershed	148.453	2.9	4.3	76.2	16.5
900	LOW	Lower Opequon Creek Remnant	145.148	1.0	3.3	89.1	6.7
910	RED	Redbud Run watershed	18.208	0.0	8.3	81.4	10.3
5001	ABR1	Lower Abrams Creek	11.578	0.0	5.1	81.7	13.2
5002	ABR2	Eastern Winchester	6.650	0.0	4.5	80.4	15.1
5003	ABR3	Lower Town Run	4.814	0.0	0.0	99.3	0.7
5004	ABR4	Upper Town Run	7.024	0.0	2.6	95.1	2.2
5005	ABR5	Southern Winchester	8.575	0.0	0.0	99.6	0.4
5006	ABR6	Upper Abrams Creek	10.878	0.3	5.8	81.7	12.1
7151	OPEadj	Upper Opequon adjusted to Abrams Creek	49.519	2.9	4.3	76.2	16.5
7153	UPPadj	Upper Opequon adjusted to Lower Opequon	361.329	2.9	4.3	76.2	16.5
7154	OPEQ	Entire (Lower) Opequon Creek watershed	361.329	1.6	4.0	83.3	11.1

Table C.5. Channel Erosion Parameters

ID#	ANCODE	developed land (%)	beef and dairy* (AU)	animal density (AU/ac.)	area-weighted CN	area-weighted KF	aFactor	Stream Length (meters) livestock access	total length	hardened length	adjusted length
	Existing Conditions										
500	ABR	38.413	225	0.0175	79.76	0.233	**0.0001807**	2,372.9	32,917.5	2961.0	**29,956.5**
715	OPE88	9.324	1090	0.0275	76.02	0.280	**0.0000551**	33,393.9	110,550.7	0.0	**110,550.7**
900	LOW	2.789	2815	0.0655	75.19	0.287	**0.0000267**	6,725.6	103,883.1	0.0	**103,883.1**
910	RED	20.160	0	0.0000	78.32	0.267	**0.0001079**	0.0	13,277.1	0.0	**13,277.1**
5001	ABR1	38.842	50	0.0167	79.09	0.200	**0.0001618**	849.0	13,579.0	0.0	**13,579.0**
5002	ABR2	46.890	0	0.0000	79.72	0.211	**0.0002067**	0.0	4,545.5	0.0	**4,545.5**
5003	ABR3	72.395	0	0.0000	84.62	0.187	**0.0003339**	0.0	2,886.0	2326.0	**560.0**
5004	ABR4	30.517	50	0.0268	78.70	0.259	**0.0001533**	187.8	3,522.5	635.0	**2,887.5**
5005	ABR5	56.643	0	0.0000	83.32	0.208	**0.0002671**	0.0	3,833.2	0.0	**3,833.2**
5006	ABR6	8.462	125	0.0414	76.17	0.306	**0.0000662**	1,336.1	4,551.3	0.0	**4,551.3**
7151	OPEadj	9.324	364	0.0283	76.02	0.280	**0.0000552**	11,139.1	36,876.1	0.0	**36,876.1**
7153	UPPadj	9.324	2653	0.0265	76.02	0.279	**0.0000546**	81,279.3	269,075.9	0.0	**269,075.9**
7154	OPEQ	11.231	4130	0.0413	76.29	0.276	**0.0000635**	42,492.4	260,628.4	2961.0	**257,667.4**
8000	LOWx	11.231	4130	0.0413	76.31	0.276	**0.0000636**	42,492.4	260,628.4	2961.0	**257,667.4**
8001	ABR1x	38.413	225	0.0175	79.75	0.233	**0.0001806**	2,372.9	32,917.5	2961.0	**29,956.5**
8002	ABR2x	38.282	175	0.0178	79.95	0.243	**0.0001864**	1,523.9	19,338.5	2961.0	**16,377.5**
8003	ABR3x	47.546	50	0.0163	81.11	0.229	**0.0002267**	187.8	6,408.5	2961.0	**3,447.5**
8005	ABR5x	29.701	125	0.0243	79.32	0.263	**0.0001548**	1,336.1	8,384.5	0.0	**8,384.5**
	Future100 Scenario										
9000	ABRf	67.332	125	0.0099	83.51	0.187	**0.0003060**	2,372.9	32,917.5	2961.0	**29,956.5**
9001	OPE88f	30.589	803	0.0206	79.50	0.249	**0.0001523**	33,393.9	110,550.7	0.0	**110,550.7**
9002	LOWf	11.350	2291	0.0582	76.72	0.273	**0.0000653**	6,725.6	103,883.1	0.0	**103,883.1**
9003	REDf	53.405	0	0.0000	84.65	0.190	**0.0002498**	0.0	13,277.1	0.0	**13,277.1**
9004	ABR1f	71.309	0	0.0000	82.77	0.167	**0.0003091**	849.0	13,579.0	0.0	**13,579.0**
9005	ABR2f	73.449	0	0.0000	82.24	0.186	**0.0003261**	0.0	4,545.5	0.0	**4,545.5**
9006	ABR3f	85.929	0	0.0000	86.31	0.162	**0.0003906**	0.0	2,886.0	2326.0	**560.0**
9007	ABR4f	59.570	0	0.0000	83.20	0.200	**0.0002759**	187.8	3,522.5	635.0	**2,887.5**
9008	ABR5f	78.205	0	0.0000	86.41	0.164	**0.0003573**	0.0	3,833.2	0.0	**3,833.2**
9009	ABR6f	24.013	125	0.0626	78.84	0.275	**0.0001343**	1,336.1	4,551.3	0.0	**4,551.3**
9010	OPEadjf	30.589	266	0.0211	79.50	0.249	**0.0001523**	11,069.0	36,644.0	0.0	**36,644.0**
9011	UPPadjf	30.589	1947	0.0199	79.50	0.246	**0.0001509**	80,977.9	268,077.9	0.0	**268,077.9**
9012	OPEQf	30.126	3219	0.0329	79.50	0.244	**0.0001484**	42,492.4	260,628.4	2961.0	**257,667.4**
9013	LOWxf	30.126	3219	0.0329	79.40	0.245	**0.0001481**	42,492.4	260,628.4	2961.0	**257,667.4**
9014	ABR1xf	67.332	125	0.0099	83.52	0.187	**0.0003060**	2,372.9	32,917.5	2961.0	**29,956.5**
9015	ABR2xf	66.187	125	0.0127	83.73	0.193	**0.0003052**	1,523.9	19,338.5	2961.0	**16,377.5**
9016	ABR3xf	73.636	0	0.0000	84.86	0.180	**0.0003371**	187.8	6,408.5	2961.0	**3,447.5**
9017	ABR5xf	57.479	125	0.0266	83.51	0.207	**0.0002721**	1,336.1	8,384.5	0.0	**8,384.5**
	Future50 Scenario										
9018	ABRx50	52.872	194	0.0152	81.64	0.210	**0.0002434**	2,372.9	32,917.5	2961.0	**29,956.5**
9019	OPE88x50	19.990	1052	0.0266	77.77	0.264	**0.0001040**	33,393.9	110,550.7	0.0	**110,550.7**
9020	LOWx50	6.928	2766	0.0663	75.93	0.280	**0.0000455**	6,725.6	103,883.1	0.0	**103,883.1**
9021	REDx50	40.155	0	0.0000	82.13	0.221	**0.0001933**	0.0	13,277.1	0.0	**13,277.1**
9022	ABR1x50	54.714	34	0.0116	80.89	0.183	**0.0002339**	849.0	13,579.0	0.0	**13,579.0**
9023	ABR2x50	60.931	0	0.0000	81.05	0.198	**0.0002698**	0.0	4,545.5	0.0	**4,545.5**
9024	ABR3x50	80.471	0	0.0000	85.63	0.172	**0.0003677**	0.0	2,886.0	2326.0	**560.0**
9025	ABR4x50	44.167	35	0.0203	80.82	0.231	**0.0002111**	187.8	3,522.5	635.0	**2,887.5**
9026	ABR5x50	68.708	0	0.0000	85.04	0.183	**0.0003176**	0.0	3,833.2	0.0	**3,833.2**
9027	ABR6x50	14.415	125	0.0498	77.19	0.294	**0.0000923**	1,336.1	4,551.3	0.0	**4,551.3**
9028	OPEadjx50	19.990	350	0.0274	77.77	0.264	**0.0001040**	11,103.9	36,759.7	0.0	**36,759.7**
9029	UPPadjx50	19.990	2556	0.0256	77.77	0.262	**0.0001029**	81,128.1	268,575.3	0.0	**268,575.3**
9030	OPEQx50	20.691	4012	0.0403	77.90	0.260	**0.0001061**	42,492.4	260,628.4	2961.0	**257,667.4**
9031	LOWxx50	20.691	4012	0.0403	77.86	0.260	**0.0001060**	42,492.4	260,628.4	2961.0	**257,667.4**
9032	ABR1xx50	52.872	194	0.0152	81.63	0.210	**0.0002434**	2,372.9	32,917.5	2961.0	**29,956.5**
9033	ABR2xx50	52.326	160	0.0162	81.85	0.218	**0.0002462**	1,523.9	19,338.5	2961.0	**16,377.5**
9034	ABR3xx50	61.373	35	0.0110	83.10	0.203	**0.0002853**	187.8	6,408.5	2961.0	**3,447.5**
9035	ABR5xx50	42.911	125	0.0254	81.31	0.236	**0.0002106**	1,336.1	8,384.5	0.0	**8,384.5**
	Future25 Scenario										
9036	ABRx25	45.642	209	0.0164	80.70	0.222	**0.0002120**	2,372.9	32,917.5	2961.0	**29,956.5**
9037	OPE88x25	14.665	1071	0.0271	76.90	0.272	**0.0000796**	33,393.9	110,550.7	0.0	**110,550.7**
9038	LOWx25	4.825	2791	0.0659	75.56	0.284	**0.0000360**	6,725.6	103,883.1	0.0	**103,883.1**
9039	REDx25	31.286	0	0.0000	80.44	0.241	**0.0001554**	0.0	13,277.1	0.0	**13,277.1**
9040	ABR1x25	46.690	42	0.0142	79.98	0.192	**0.0001975**	849.0	13,579.0	0.0	**13,579.0**
9041	ABR2x25	54.117	0	0.0000	80.41	0.204	**0.0002392**	0.0	4,545.5	0.0	**4,545.5**
9042	ABR3x25	76.866	0	0.0000	85.18	0.179	**0.0003526**	0.0	2,886.0	2326.0	**560.0**
9043	ABR4x25	37.142	43	0.0237	79.73	0.245	**0.0001814**	187.8	3,522.5	635.0	**2,887.5**
9044	ABR5x25	63.057	0	0.0000	84.23	0.195	**0.0002939**	0.0	3,833.2	0.0	**3,833.2**
9045	ABR6x25	11.126	125	0.0452	76.63	0.301	**0.0000779**	1,336.1	4,551.3	0.0	**4,551.3**
9046	OPEadjx25	14.665	357	0.0279	76.90	0.272	**0.0000796**	11,121.5	36,817.8	0.0	**36,817.8**
9047	UPPadjx25	14.665	2605	0.0261	76.90	0.270	**0.0000788**	81,203.6	268,825.2	0.0	**268,825.2**
9048	OPEQx25	15.964	4071	0.0408	77.10	0.268	**0.0000848**	42,492.4	260,628.4	2961.0	**257,667.4**
9049	LOWxx25	15.964	4071	0.0408	77.09	0.268	**0.0000848**	42,492.4	260,628.4	2961.0	**257,667.4**
9050	ABR1xx25	45.642	209	0.0164	80.69	0.222	**0.0002120**	2,372.9	32,917.5	2961.0	**29,956.5**
9051	ABR2xx25	45.327	168	0.0170	80.90	0.231	**0.0002164**	1,523.9	19,338.5	2961.0	**16,377.5**
9052	ABR3xx25	54.673	43	0.0136	82.13	0.216	**0.0002569**	187.8	6,408.5	2961.0	**3,447.5**
9053	ABR5xx25	36.148	125	0.0248	80.29	0.250	**0.0001820**	1,336.1	8,384.5	0.0	**8,384.5**

* No. of Beef and Dairy reduced by the % of pasture reduced by accompanying buildout.

Table C.6. Other GWLF Land Use-Specific Parameters

Land Use	Description	Runoff Curve Numbers HSG=A	HSG=B	HSG=C	HSG=D	C-factor	ET Cover Coefficient (dormant)	(growing)	Sediment Buildup Rate (kg/ha-day)
Hi-Till	Frederick County	69.2	79.2	86.4	89.8	0.352	0.40	1.00	
Lo-Till	Frederick County	67.3	77.3	84.5	87.7	0.155	0.55	1.00	
pasture1	pasture, good or improved	39	61	74	80	0.003	1.00	1.00	
pasture2	pasture, fair or unimproved	49	69	79	84	0.013	1.00	1.00	
pasture3	pasture, poor or overgrazed	68	79	86	89	0.071	1.00	1.00	
open urban	close-seeded…,contour, good	55	69	78	83	0.013	1.00	1.00	
orchard	orchard, fair, 20-40% canopy	43	65	76	82	0.001	0.30	1.00	
forest	woods, fair	36	60	73	79	0.0005	0.51	1.00	
transitional	fallow, bare soil	77	86	91	94	0.175	0.30	0.30	
LDR-pur	low intensity residential, 88% pervious	46	65	77	82	0.003	1.00	1.00	1.30
MDR-pur	med intensity residential, 70% pervious	57	72	81	86	0.003	1.00	1.00	1.10
HDR-pur	high intensity residential, 35% pervious	77	85	90	92	0.003	1.00	1.00	2.20
Com-pur	high intensity commercial, 21% pervious	85	90	92	94	0.003	1.00	1.00	0.80
LDR-imp	low intensity residential, 12% impervious	76	85	89	91		0.00	0.00	2.50
MDR-imp	med intensity residential, 30% impervious	98	98	98	98		0.00	0.00	6.20
HDR-imp	high intensity residential, 65% impervious	98	98	98	98		0.00	0.00	3.90
Com-imp	high intensity commercial, 79% impervious	98	98	98	98		0.00	0.00	2.80

Table C.7. Sediment Loads by Sub-Watershed – Abrams Creek and Area-adjusted Upper Opequon

Existing Scenario Sediment Loads (t/yr)

Landuse	ABR1x	ABR2x	ABR3x	ABR4	ABR5x	ABR6	OPE88	Area-adjusted Upper Opequon OPEadj	Abrams Creek ABRsdr*
hit	-3.3	10.0	0.0	0.0	126.5	631.5	5,117.6	2,362.7	764.8
lot	-1.1	3.3	0.0	0.0	43.6	208.1	2,289.3	1,056.9	253.9
pa1	34.4	10.4	-0.3	48.4	10.8	80.1	638.6	294.8	183.9
pa2	46.0	20.5	0.0	0.7	7.3	61.7	509.0	235.0	136.2
pa3	0.0	0.0	0.0	0.0	0.0	0.0	68.8	31.8	0.0
urbg	62.8	112.2	80.9	24.0	127.1	34.2	212.0	97.9	441.3
orch	-0.1	0.3	0.0	11.2	0.5	12.8	26.5	12.2	24.8
for	8.7	5.1	1.7	5.4	3.5	11.8	108.2	50.0	36.1
tran	56.7	47.5	0.0	0.0	0.0	348.6	1,093.1	504.7	452.8
L-pur	2.1	0.2	0.0	1.0	1.0	5.3	31.6	14.6	9.6
M-pur	27.3	22.5	16.4	6.9	20.0	4.8	56.2	25.9	97.9
H-pur	1.6	0.9	0.0	6.0	1.2	0.3	0.9	0.4	10.1
Com-pur	3.6	2.4	6.7	3.7	10.5	1.9	11.4	5.3	28.8
L-imp	0.4	0.2	0.0	0.0	0.0	0.6	11.3	3.8	1.3
M-imp	80.1	62.3	0.2	0.9	1.5	6.3	259.0	86.4	151.3
H-imp	12.6	10.8	0.0	2.6	0.3	1.1	22.4	7.5	27.5
Com-imp	58.4	38.2	0.3	1.7	3.5	8.3	209.4	69.8	110.4
Chan	2,922.6	1,603.7	224.9	139.7	647.7	109.6	8,468.6	1,464.5	5,648.3
% tran in MS4	16.0%	23.0%	99.5%	91.1%	96.1%	27.9%			
% imp in MS4	0.0%	7.7%	0.0%	0.0%	100.0%	0.0%			
MS4	28.8	37.3	93.2	53.4	307.9	6.3	0.0	0.0	527.0
PS	0.0	0.0	0.2	0.0	0.9	0.4	9.0	3.0	1.5
Total	**3,341.9**	**1,988.3**	**425.2**	**306.6**	**1,315.9**	**1,534.1**	**19,143.0**	**6,327.3**	**8,907.4**

Future50 Scenario Sediment Loads (t/yr)

Landuse	ABR1xx50	ABR2xx50	ABR3xx50	ABR4x50	ABR5xx50	ABR6x50	OPE88x50	Area-adjusted Upper Opequon OPEadjx50	Abrams Creek ABRsdr*
hit	-1.7	3.4	0.0	0.0	112.4	592.6	5,109.8	2,354.0	706.7
lot	-0.6	1.1	0.0	0.0	38.8	195.3	2,285.9	1,053.1	234.7
pa1	24.4	6.9	-0.5	34.2	7.1	57.2	557.0	256.6	129.4
pa2	27.8	12.0	0.0	0.4	4.1	37.8	424.3	195.5	82.1
pa3	0.0	0.0	0.0	0.0	0.0	0.0	60.2	27.8	0.0
urbg	63.4	110.8	80.3	24.1	127.5	34.7	211.7	97.5	440.9
orch	-0.1	0.2	-0.1	9.9	0.4	11.4	25.5	11.7	21.8
for	5.7	3.2	1.1	3.5	2.2	7.7	90.2	41.6	23.4
tran	57.7	43.3	0.0	0.0	0.0	353.7	1,091.5	502.8	454.8
L-pur	3.0	0.3	-0.1	1.5	1.3	7.8	44.5	20.5	13.8
M-pur	37.9	30.7	22.4	9.5	27.8	6.7	122.3	56.4	135.0
H-pur	2.2	1.2	-0.1	8.2	1.6	0.4	2.3	1.0	13.5
Com-pur	5.0	3.2	9.2	5.0	14.6	2.7	24.5	11.3	39.6
L-imp	0.6	0.3	0.0	0.0	0.0	0.8	15.9	5.3	1.8
M-imp	110.6	86.1	0.3	1.2	2.1	8.7	564.8	187.8	209.0
H-imp	17.0	14.6	0.0	3.5	0.4	1.5	53.7	17.8	37.1
Com-imp	80.4	52.6	0.4	2.3	4.8	11.4	450.5	149.8	152.0
Chan	3,982.8	2,129.8	292.2	185.4	872.2	126.3	16,618.4	2,854.2	7,588.7
% tran in MS4	16.0%	23.0%	99.5%	91.1%	96.1%	27.9%			
% imp in MS4	0.0%	7.7%	0.0%	0.0%	100.0%	0.0%			
MS4	39.6	49.6	128.4	72.9	354.6	8.7	0.0	0.0	653.7
PS	0.0	0.0	2.5	0.0	20.7	4.1	87.5	29.2	27.4
Total	**4,456.3**	**2,549.5**	**537.0**	**362.6**	**1,594.5**	**1,470.0**	**27,840.4**	**7,873.8**	**10,965.2**

Future100 Scenario Sediment Loads (t/yr)

Landuse	ABR1xf	ABR2xf	ABR3xf	ABR4f	ABR5xf	ABR6f	OPE88f	OPEadjf	ABRsdr*
hit	-0.7	-1.9	0.0	0.0	99.2	552.3	5,102.2	2,345.4	648.9
lot	-0.2	-0.6	0.0	0.0	34.3	182.0	2,282.4	1,049.2	215.5
pa1	14.2	3.8	-0.5	19.9	3.9	33.7	475.6	218.6	75.0
pa2	9.5	4.0	0.0	0.1	1.3	13.1	340.0	156.3	28.1
pa3	0.0	0.0	0.0	0.0	0.0	0.0	51.7	23.8	0.0
urbg	63.9	109.8	79.6	24.1	127.9	35.2	211.4	97.2	440.5
orch	0.0	0.1	-0.1	8.5	0.2	10.0	24.5	11.3	18.8
for	2.6	1.4	0.5	1.6	1.0	3.6	72.2	33.2	10.6
tran	58.4	39.5	0.0	0.0	0.0	358.8	1,089.9	501.0	456.7
L-pur	4.0	0.3	-0.1	2.0	1.7	10.3	57.3	26.3	18.0
M-pur	48.4	39.0	28.3	12.2	35.6	8.7	188.3	86.6	172.2
H-pur	2.8	1.5	-0.2	10.3	2.1	0.5	3.6	1.6	17.0
Com-pur	6.5	3.9	11.6	6.4	18.6	3.4	37.5	17.3	50.4
L-imp	0.8	0.4	0.0	0.0	0.0	1.1	20.5	6.8	2.4
M-imp	141.2	109.8	0.3	1.5	2.7	11.2	870.6	288.6	266.7
H-imp	21.4	18.3	0.0	4.4	0.5	1.9	85.0	28.2	46.6
Com-imp	102.4	67.0	0.5	3.0	6.1	14.5	691.7	229.3	193.5
Chan	5,030.2	2,619.8	344.6	236.2	1,107.3	151.0	25,339.3	4,330.1	9,489.2
% tran in MS4	16.0%	23.0%	99.5%	91.1%	96.1%	27.9%			
% imp in MS4	0.0%	7.7%	0.0%	0.0%	100.0%	0.0%			
MS4	50.5	61.8	163.6	92.3	401.4	11.1	0.0	0.0	780.6
PS	0.0	0.0	2.5	0.0	20.7	4.1	87.5	29.2	27.4
Total	**5,556.0**	**3,078.1**	**631.6**	**423.6**	**1,866.5**	**1,406.7**	**37,031.1**	**9,479.8**	**12,958.0**

Future25 Scenario Sediment Loads (t/yr)

Landuse	ABR1xx25	ABR2xx25	ABR3xx25	ABR4x25	ABR5xx25	ABR6x25	UPPadjx25	OPEadjx25	ABRsdr*
hit	-2.7	7.1	0.0	0.0	119.3	612.1	5,116.3	2,358.4	735.7
lot	-0.9	2.3	0.0	0.0	41.1	201.7	2,288.7	1,055.0	244.3
pa1	29.4	8.7	-0.5	41.3	8.9	68.7	598.0	275.7	156.6
pa2	36.9	16.2	0.0	0.6	5.6	49.8	466.8	215.2	109.1
pa3	0.0	0.0	0.0	0.0	0.0	0.0	64.6	29.8	0.0
urbg	63.0	111.7	80.5	24.1	127.3	34.5	211.9	97.7	441.0
orch	-0.1	0.2	0.0	10.5	0.5	12.1	26.0	12.0	23.3
for	7.2	4.1	1.4	4.5	2.8	9.8	99.3	45.8	29.7
tran	57.0	45.7	0.0	0.0	0.0	351.1	1,092.9	503.8	453.8
L-pur	2.6	0.3	-0.1	1.3	1.2	6.5	38.1	17.6	11.7
M-pur	32.5	26.7	19.4	8.2	23.9	5.7	89.3	41.2	116.4
H-pur	1.9	1.0	0.0	7.1	1.4	0.3	1.6	0.7	11.8
Com-pur	4.3	2.8	7.9	4.4	12.6	2.3	18.0	8.3	34.2
L-imp	0.5	0.3	0.0	0.0	0.0	0.7	13.6	4.5	1.5
M-imp	95.4	74.2	0.2	1.0	1.8	7.5	411.9	137.2	180.2
H-imp	14.8	12.7	0.0	3.1	0.4	1.3	38.0	12.7	32.3
Com-imp	69.4	45.4	0.3	2.0	4.1	9.9	330.0	109.9	131.2
Chan	3,453.6	1,867.8	259.8	162.2	758.7	117.6	12,498.1	2,152.0	6,619.9
% tran in MS4	16.0%	23.0%	99.5%	91.1%	96.1%	27.9%			
% imp in MS4	0.0%	7.7%	0.0%	0.0%	100.0%	0.0%			
MS4	34.2	43.5	110.8	63.1	331.2	7.5	0.0	0.0	590.3
PS	0.0	0.0	2.5	0.0	20.7	4.1	87.5	29.2	27.4
Total	**3,899.3**	**2,271.0**	**483.4**	**334.3**	**1,463.4**	**1,503.6**	**23,490.6**	**7,106.4**	**9,950.5**

* ABRsdr is calculated as the sumproduct of loads from component sub-watersheds and the ratio of SDR from the entire watershed divided by the SDR from the individual sub-watersheds.

Table C.8. Sediment Loads by Sub-Watershed – Lower Opequon Creek and Area-adjusted Upper Opequon

	Existing Scenario Sediment Loads (t/yr)				Area-adjusted Upper Opequon	Lower Opequon
Landuse	**ABRsdr**	**LOWx**	**RED**	**OPE88**	**UPPadj**	**OPEQsdr***
hit	423.5	4,068.3	268.4	3,930.3	9,605.9	8,690.5
lot	140.6	881.4	88.4	1,758.2	3,323.6	2,868.7
pa1	101.8	390.1	70.5	490.4	1,051.4	1,052.8
pa2	75.4	191.8	73.5	390.9	877.3	731.6
pa3	0.0	107.9	19.7	52.9	163.5	180.5
urbg	244.4	2.0	122.9	162.8	425.4	532.1
orch	13.7	12.2	4.2	20.4	54.2	50.4
for	20.0	-22.7	13.0	83.1	172.0	93.4
tran	250.8	547.8	19.6	839.5	1,314.6	1,657.7
L-pur	5.3	28.8	7.1	24.3	58.4	65.5
M-pur	54.2	24.8	5.8	43.2	119.8	127.9
H-pur	5.6	1.9	0.7	0.7	4.1	9.0
Com-pur	16.0	6.3	6.4	8.8	23.0	37.4
L-imp	0.7	18.4	0.8	7.9	27.5	27.7
M-imp	83.8	229.8	8.8	180.2	630.5	502.5
H-imp	15.2	40.2	3.2	15.5	54.4	74.2
Com-imp	61.1	296.4	45.6	145.6	509.6	548.7
Chan	5,648.3	25,280.5	632.2	8,468.6	35,324.5	40,029.6
% tran in MS4			12.0%	9.4%		
% imp in MS4			0.0%	0.0%		
MS4	291.8	0.0	7.9	36.4	0.0	336.2
PS	1.5	20.9	0.1	9.0	21.8	31.5
Total	**7,453.8**	**32,126.7**	**1,398.8**	**16,668.7**	**53,761.4**	**57,647.8**

	Future50 Scenario Sediment Loads (t/yr)				Area-adjusted Upper Opequon	Lower Opequon
Landuse	**ABRsdr**	**LOWxx50**	**REDx50**	**OPE88x50**	**UPPadjx50**	**OPEQsdr***
hit	391.4	3,802.5	241.6	3,924.3	9,583.1	8,359.8
lot	130.0	794.6	79.6	1,755.5	3,315.7	2,759.7
pa1	71.6	365.4	61.6	427.7	916.3	926.5
pa2	45.5	187.8	65.8	325.9	730.8	624.9
pa3	0.0	106.9	19.0	46.3	143.0	172.2
urbg	244.1	6.2	118.8	162.6	424.3	531.8
orch	12.1	11.3	3.6	19.6	52.1	46.6
for	12.9	-14.3	11.5	69.3	143.2	79.4
tran	251.9	549.1	19.0	838.3	1,311.5	1,658.1
L-pur	7.7	43.3	10.2	34.2	82.1	95.3
M-pur	74.8	50.8	14.8	94.0	260.5	234.4
H-pur	7.5	3.5	1.6	1.7	9.8	14.4
Com-pur	21.9	11.5	15.4	18.8	49.3	67.7
L-imp	1.0	27.1	1.1	11.1	38.6	40.3
M-imp	115.7	442.0	23.4	392.8	1,372.1	973.9
H-imp	20.5	63.5	7.6	37.3	130.4	129.0
Com-imp	84.2	582.6	114.0	313.3	1,094.6	1,094.1
Chan	7,588.7	42,877.3	1,467.7	16,618.4	68,832.3	68,552.0
% tran in MS4			12.0%	9.4%		
% imp in MS4			0.0%	0.0%		
MS4	362.0	0.0	19.9	78.7	0.0	460.6
PS	27.4	508.2	0.1	87.5	213.0	623.2
Total	**9,470.8**	**50,419.5**	**2,296.7**	**25,257.3**	**88,702.7**	**87,444.0**

	Future100 Scenario Sediment Loads (t/yr)					
Landuse	**ABRsdr**	**LOWxf**	**REDf**	**OPE88f**	**UPPadjf**	**OPEQsdr***
hit	359.3	3,525.1	216.8	3,918.5	9,548.5	8,019.7
lot	119.3	704.0	71.4	1,752.9	3,303.8	2,647.6
pa1	41.5	339.1	53.4	365.3	780.8	799.3
pa2	15.5	182.4	58.7	261.1	584.3	517.7
pa3	0.0	105.6	18.4	39.7	122.4	163.7
urbg	244.0	9.5	115.0	162.3	422.8	530.8
orch	10.4	10.3	3.1	18.8	49.9	42.7
for	5.9	-6.1	10.1	55.5	114.4	65.3
tran	252.9	548.1	18.4	837.0	1,306.7	1,656.4
L-pur	10.0	57.8	13.1	44.0	105.5	124.9
M-pur	95.3	77.1	23.3	144.6	400.1	340.4
H-pur	9.4	5.2	2.5	2.7	15.4	19.8
Com-pur	27.9	17.3	23.9	28.8	75.4	98.0
L-imp	1.3	35.9	1.5	14.3	49.7	53.0
M-imp	147.7	654.2	38.0	605.4	2,111.0	1,445.3
H-imp	25.8	86.9	12.0	59.1	206.0	183.8
Com-imp	107.2	868.9	182.4	481.1	1,677.4	1,639.5
Chan	9,489.2	60,965.1	2,251.4	25,339.3	103,887.7	98,045.1
% tran in MS4			12.0%	9.4%		
% imp in MS4			0.0%	0.0%		
MS4	432.3	0.0	31.8	121.0	0.0	585.1
PS	27.4	508.2	0.1	87.5	213.0	623.2
Total	**11,422.3**	**68,694.7**	**3,145.5**	**34,339.0**	**124,974.9**	**117,601.3**

	Future25 Scenario Sediment Loads (t/yr)					
Landuse	**ABRsdr**	**LOWxx25**	**REDx25**	**UPPadjx25**	**UPPadjx25**	**OPEQsdr***
hit	407.4	3,933.6	254.8	3,929.3	9,594.6	8,525.1
lot	135.3	837.2	84.0	1,757.7	3,319.7	2,814.2
pa1	86.7	377.6	66.0	459.3	983.8	989.6
pa2	60.4	189.7	69.6	358.5	804.0	678.3
pa3	0.0	107.4	19.4	49.6	153.3	176.3
urbg	244.2	4.1	120.8	162.8	424.9	531.9
orch	12.9	11.7	3.9	20.0	53.1	48.5
for	16.5	-18.6	12.2	76.2	157.6	86.4
tran	251.3	548.0	19.3	839.3	1,313.0	1,657.9
L-pur	6.5	36.0	8.7	29.3	70.3	80.4
M-pur	64.5	37.7	10.4	68.6	190.2	181.2
H-pur	6.5	2.7	1.2	1.2	6.9	11.7
Com-pur	19.0	8.8	11.0	13.8	36.1	52.5
L-imp	0.8	22.8	0.9	9.5	33.1	34.0
M-imp	99.8	335.9	16.1	286.5	1,001.7	738.2
H-imp	17.9	51.9	5.4	26.4	92.4	101.6
Com-imp	72.6	439.5	79.8	229.5	802.4	821.4
Chan	6,619.9	34,038.0	1,052.7	12,498.1	51,956.0	54,208.6
% tran in MS4			12.0%	9.4%		
% imp in MS4			0.0%	0.0%		
MS4	326.9	0.0	13.9	57.6	0.0	398.4
PS	27.4	508.2	0.1	87.5	213.0	623.2
Total	**8,476.5**	**41,472.3**	**1,850.2**	**20,960.7**	**71,206.0**	**72,759.5**

* OPEQsdr is calculated as the sumproduct of loads from component sub-watersheds and the ratio of SDR from the entire watershed divided by the SDR from the individual sub-watersheds.

APPENDIX D. ACCOUNTING FOR BMPS

The BMP acres in Table D.1 come from DCR's Cost-Share Program database, and are reported by state Hydrologic Unit Program (HUP) watershed. The sediment reduction efficiencies are those used by the Chesapeake Bay Program in conjunction with the Chesapeake Bay Watershed Model to account for installed BMPs in each of the states within the Chesapeake Bay drainage. The aggregate HUP sediment reduction efficiencies in Table D.2 were then calculated by multiplying the number of BMP acres for each BMP divided by the total number of acres of each landuse times the sediment reduction factor, and summing for each land use, the reduction fractions for each BMP applied to that landuse. For TMDL modeling, these reductions are actually applied as passthrough fractions (1 – sediment reduction fractions), and applied to modeled loads. The passthrough fractions used in TMDL modeling are from the HUP containing the majority of the TMDL watershed's area (Abrams Creek – B09; Upper Opequon – B08); Lower Opequon Remnant – B09).

Table D.1. Acres of BMPs and Sediment Reduction Efficiencies/Acre

Land Use	BMP	BMP Acres B08	BMP Acres B09	SED Reduction Efficiency
High Till	Cover Crop	78.92	22.51	0.15
Low Till	Cover Crop	60.48	17.19	0.15
Manure Acres	Animal Waste Management	0.00	0.78	0
Pasture	Stream Protection w/ Fencing	0.00	6.19	0.75
Pasture, Cattle Grazed	Stream Protection w/ Fencing	0.00	1.25	0.75
Pasture	Grazing Land Protection	0.10	459.52	0
Pasture, Cattle Grazed	Grazing Land Protection	0.01	92.68	0
High Till	Nutrient Management	10.76	342.73	0
Low Till	Nutrient Management	8.24	261.67	0
Hay	Nutrient Management	562.00	234.20	0
High Till	Farm Plans/SCWQP	1.16	1.53	0.4
Low Till	Farm Plans/SCWQP	0.89	1.17	0.08
Hay	Farm Plans/SCWQP	5.65	6.86	0.08
Pasture	Farm Plans/SCWQP	7.41	8.11	0.14
Pasture, Cattle Grazed	Farm Plans/SCWQP	0.43	1.64	0.14

Table D.2. Aggregate HUP Sediment Reduction Efficiencies

Land Use	B08	B09
High Till	0.008454	0.001588
Low Till	0.008201	0.001393
Hay	6.37E-05	4.86E-05
Pasture	0.000111	0.000433
Pasture, Cattle Grazed	0.000111	0.000433
Pasture, Poultry Litter	0	0
Manure Acres	0	0
Forestry	0	0
Disturbed Forest	0.255	0.255
Pervious Urban	0	0
Impervious Urban	0	0